PETROBRAS	TECHNICAL SPECIFICATION	Nº: I–ET–0000.00–0000–290–P9U–004		
	CLIENT: E&P		SHEET: 1 of 61	
	JOB: GENERAL		CC	
	ÁREA: GENERAL		PROJECT:	
DP&T	TÍTLE: TITANIUM STRESS JOINTS SPECIFICATION		P	
			SUB/ES/EDD/EDR	

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I N D E X O F R E V I S I O N S

REV.	D E S C R I P T I O N A N D / O R R E V I S E D S H E E T S
0	**ORIGINAL**
A	INCLUDED: Project responsibilities, sec. 1.2; Definitions and abbreviations, sec. 2; References, sec. 3; Material selection requirements, sec. 6.1; Electrical isolation requirement for Compact Flange studs, sec. 7.1; Dimensional requirements for flange elevation, gaps with receptacle and inner diameter transition, sec. 7.2; Design load category and load selection and sources of misalignments to be considered, sec. 7.4; Fatigue requirement on curves, sec. 7.6; More detailed ECA requirements, sec. 7.9; Requirements for steel studs corrosion protection and CRA overlay for galvanic compatibility with steel parts, sec. 7.15; Requirements for steel forgings, sec. 8.5; Requirements for CRA weld overlay in steel parts, 8.6; Testing requirements for steel parts, sec. 10; Electric isolation and leak test for FAT, sec. 11.1; Rubber coating qualification requirements, sec. 12.1.2; List of documents for bidding phase and final documentation, sec. 13.2. ALTERED: Scope, sec. 1.1; System description, sec. 1.3; List of scope of supply, sec. 4.1; Functional requirements for TSJ assembly, external coating, Adapter Bushing, and compact flange, sec. 5; Limit temperature for non-NACE alloy, Table 7.1; Explicitly define critical section for fatigue and Basic Design data, sec. 7.7; Pigging requirements, sec. 7.12; Technology qualifications, sec. 12; Inspection and maintenance manual, sec. 13.3; Requirement for drawings information, sec. 13.4. EXCLUDED: Titanium welding, weld inspection, weld qualification and PWHT requirements. GENERAL REVISION of the text for clarity.
B	INCLUDED: Reference [6], Project Metocean Data; requisition for Compact Flange assembly/ torqueing procedure, sec. 5.4; new load cases, and requirement for fluid combination in sec.7.4; interface loads requirements, sec. 7.4.1; Thermal Analysis requirements, sec 7.8; Chemical Compatibility Testing requirements, sec. 9.5; base metal qualification matrix notes, sec. 12.1.1; Compact Flange assembly, torqueing and pre-loading procedure to be reported within the final documentation, sec. 13.2. ALTERED: hydrostatic test pressure, sec. 11.1.1; numbering of other references from **Erro! Fonte de referência não encontrada.**; General revision of the text for clarity where highlighted. EXCLUDED: IX seal ring type, sec. 5.1.
C	INCLUDED: Stress Joint for Support-Tube (Figure 1.2); Definitions and Abbreviations; References; Dummy HOA in Scope of Supply, Table 4.1. ALTERED: Functional requirements for Compact Flange (sec. 5.4); Qualification Scope of Metallic Parts, sec. 12.1.1. EXCLUDED: Reference ISO12736; External Coating Qualification, sec. 12.1.2 (requirements transferred to ref. [5]); Lifting test requirements, sec. 13.7. GENERAL REVISION of the text for clarity.
D	INCLUDED: reference to annex D2.4 of [52] for local failure criteria of titanium and steel flanges, sec. 5.4; Images of the Flange Elevation for Support-Tube (Figure 7.1) and the "Dummy HOA" (Figure 7.2), sec 7.2; Hydrotest (“Temporary 1”) Design Case, Table 7.1; reference to the Inspection Manual of sec. 13.3 (deliverable) in sec. 7.10 and sec. 7.11; Corrosion protection requirement for the Transition pool in steel pipe, sec. 7.15; Explanation on qualification and PQT scope of work, as well as the Note 1 and the Table 12.1, in sec. 12.1.1. ALTERED: titles of ref. [2] and [3] in Project’s reference list sec. 3.1; code of ref. [10], in sec 3.2; term “optional” to “optative” (supplied items) and note for confirmation of supply, Table 4.1; Some steel parts’ material specifications in Material Requirements, Table 6.1; Name of the Load Category “Temporary” to “Temporary 2” (Installation), and renumbered all the Design Cases, Table 7.1; Qualification section 12; Moved the text with requirement for Ti alloy composition in term of interstitial elements from note 5 of sec 12.1.1 to sec. 8.1.2; Renumbered Notes in sec. 12.1.1. EXCLUDED: abbreviation for PPT, sec. 2.2; “Project Management” section 13.5 (entirety). GENERAL REVISION of the text for clarity.

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H
DATE	29/11/2017	21/05/2020	20/08/2020	17/12/2020	29/04/2021				
PROJECT	EISE/EDR	EISE/EDR	EISE/EDR	EISE/EDR	EDD/EDR				
EXECUTION	TS8H	TS8H; UQ0G; SG5H	TS8H	TS8H	TS8H				
CHECK	BF6I	BW12; CSM6, RVYZ	UQ0G/CSM6	UP86	UP86				
APPROVAL	CLZ2	CLZ2	CLZ2	CLZ2	CLZ2				

TABLE OF CONTENTS

1. INTRODUCTION

1.1. SCOPE OF THIS DOCUMENT

The purpose of this specification is to define the minimum functional and technical requirements for the design, material selection, manufacture, inspection, testing and delivery of Titanium Stress Joints to connect rigid risers to the FPU Hang–off.

This document shall be read in conjunction with all documents listed in Section 3.

Additional or amended functional requirements for Stress Joint can be found within the Project documentation. The project detailed scope of supply, information on the Hang–off and interface with the FPU, definition of the allowed type of top connection, coating specification, loads, operating conditions and fluids composition and other Project related data are also defined in project documentation [1] to [9].

1.2. PROJECT DOCUMENTATION AND RESPONSABILITIES

There are, basically, two different ways Stress Joints can be purchased to PETROBRAS projects the way the component will be purchased implies the responsibilities between SUPPLIER, CONTRACTOR and PETROBRAS. In both cases, the procurement will happen through a competitive process (bid).

The first alternative is PETROBRAS purchasing the component directly from the SUPPLIER. In this case, the SUPPLIERs will present technical and commercial proposals directly to PETROBRAS during the bidding process, and the contract will be signed between PETROBRAS and SUPPLIER. In this case, the CONTRACTOR will be contracted in a similar process, and there will be no commercial relationship between SUPPLIER and CONTRACTOR. When this purchasing strategy is chosen, PETROBRAS is responsible for supply all the final inputs to the component design, being responsible for issuing all the Project documentation ([1] to [5]). In this case, PETROBRAS is also responsible for the interface between SUPPLIER and CONTRACTOR.

Alternatively, PETROBRAS may choose to include the TSJ procurement in CONTRACTOR's scope (this method of contract is usually referred to as EPCI). In this case, the contractual relationships are between CONTRACTOR and SUPPLIER, and between CONTRACTOR and PETROBRAS. When this purchasing strategy is chosen, the interface between the TSJ, riser and receptacle cast is entirely within CONTRACTOR scope. The definitive inputs for component design are a CONTRACTOR responsibility. CONTRACTOR is also responsible for issuing its own version of the documents [2] to [5], as well as a TSJ specification, to SUPPLIER, in compliance with the PETROBRAS documentation.

Its highlighted that, in this second strategy, PETROBRAS may also issue in the bidding process the documents of [2] to [5] based on the results of the basic design process. These documents may be used in part or in whole as reference for preliminary sizing during the bidding phase, under CONTRACTOR responsibility. Additionally, SUPPLIER shall be aware that the riser configuration to be defined by the CONTRACTOR may not be the same configuration defined by PETROBRAS in the basic design.

The definition of the final component datasheet, with definitive interface loads, is under CONTRACTOR responsibility. PETROBRAS has no responsibility for changes in design due to differences between PETROBRAS and CONTRACTOR's datasheets.

This technical specification applies to both ways of purchasing.

Scope of supply in this technical specification is amended by Material Requisition/ Data Basis regarding definition whether it includes or not any optional parts, as per section 4.1.

1.3. SYSTEM DESCRIPTION

The *Stress Joint* can be seated on a *Conical Receptacle* or hung on a *Support–Tube* type through a *Hang–off Adaptor* (HOA), designed as per [10]. The definitions of the type(s) of *Hang–off* selected for the Project is given in [2].

A Stress Joint will include an *Extension* ("dynamic section") with an active taper section, *a Head* ("static section") seated on a steel *Adapter Bushing* (with or without a conical *Steel Bushing*), or a HOA, to react riser tension, an *Upper Compact Flange* attached to a steel *Transition Spool* for the top connection above the *Hang–off*, and a *Lower Compact Flange* with or without a *Pup Piece*, which is welded to the top of the first riser pipe.

Figure 1.1 presents a general illustration of a *Titanium Stress Joint* for *Conical Receptacle*, and Figure 1.2 shows the TSJ for *Support–Tube*. The major elements are labelled for reference and some terminologies used in this document are introduced.

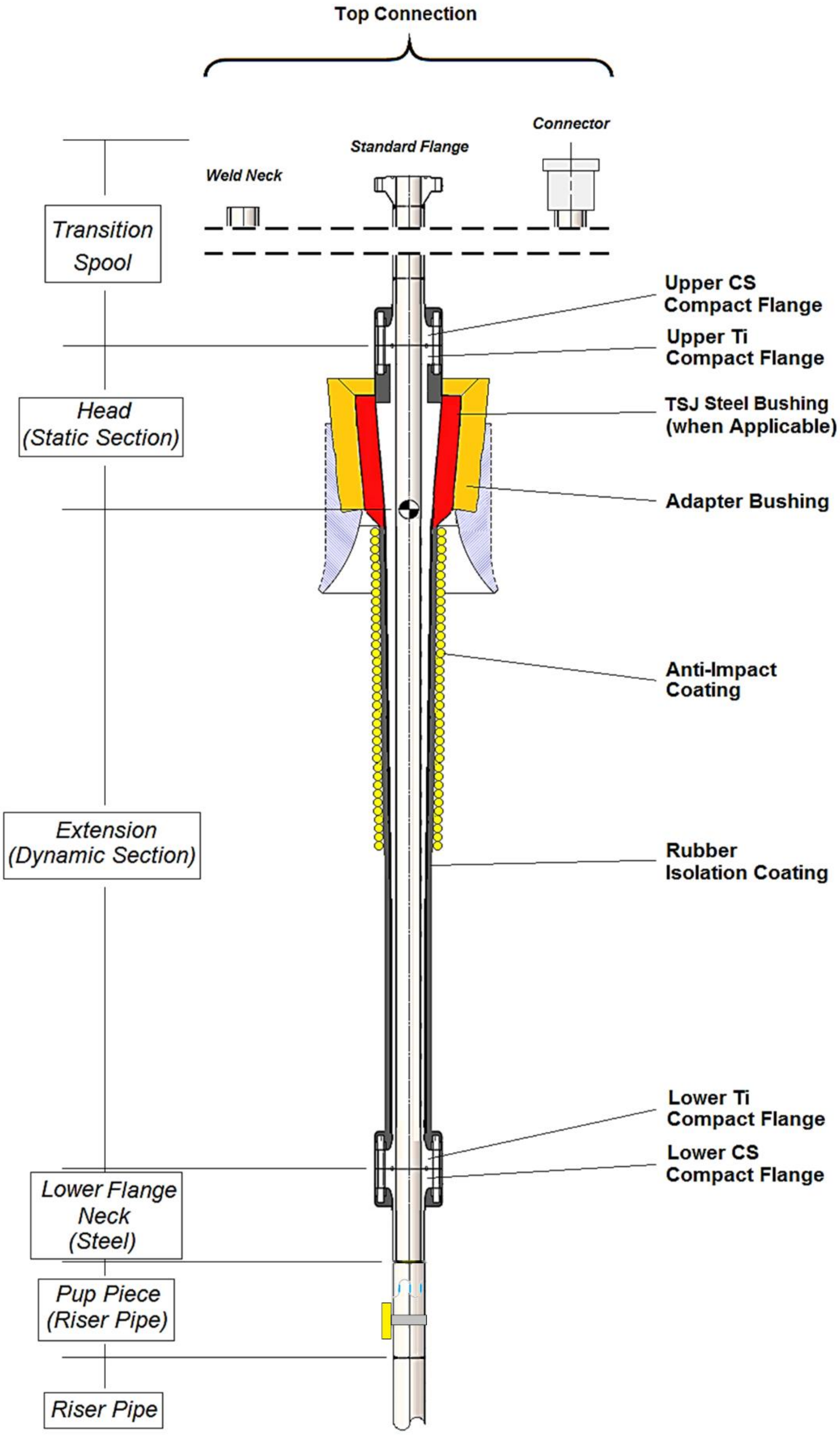

Figure 1.1 – Schematic View of the *Titanium Stress Joint* for Conical Receptacle and its Main Parts.

NOTE: Concept of the parts and/ or configuration depicted in Figure 1.1 may vary according to SUPPLIER TSJ design.

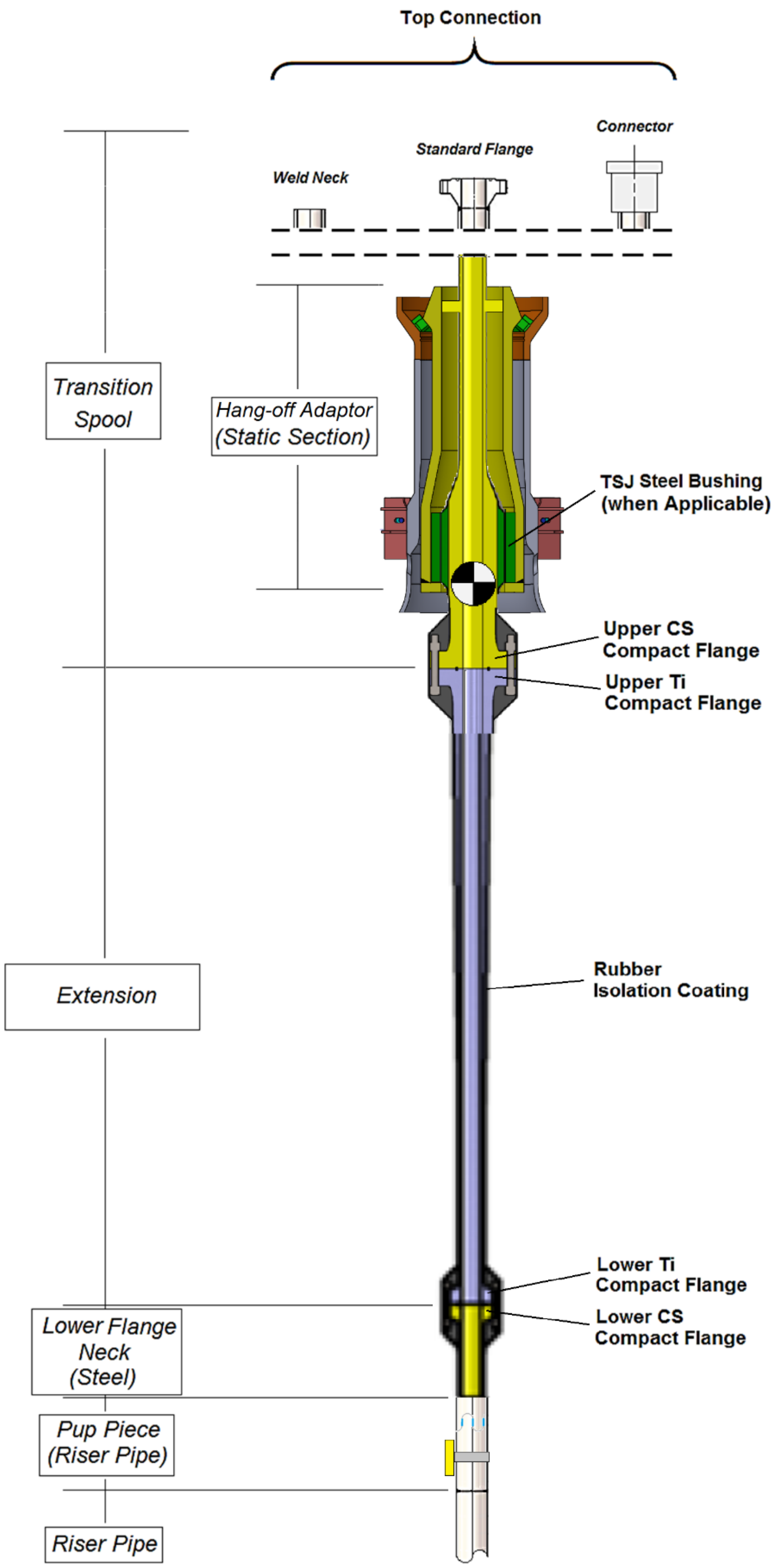

Figure 1.2 – Schematic View of the *Titanium Stress Joint* for *Support–Tube* and its Main Parts.

NOTE: Concept of the parts and/ or configuration depicted in Figure 1.2 may vary according to the *Support–Tube* selected for the Project and SUPPLIER TSJ design.

The function of the Titanium Stress Joint is to:

- Support the riser;
- Provide an articulated interface between the FPU and the riser, to allow for relative angular motion between the FPU and the riser, while providing adequate flexibility to limit the transference of loads (mainly bending moments) in the top area of the riser and to the lower balcony structure;
- Provide an interface between the riser and the FPU piping for fluid transportation in the maximum operating condition of pressure and temperature;
- Allows pigs to be transported between FPU piping and the riser;
- Connect the riser to temporary installation equipment (ex: pig launch and receiver or pull in head) during pull in and commissioning activities;

2. DEFINITIONS AND ABBREVIATIONS

2.1. DEFINITIONS

PETROBRAS	PETRÓLEO BRASILEIRO S/A. – PETROBRAS Where referred to in this Specification, it means both the Company itself and its employees authorized to communicate with CONTRACTOR or SUPPLIER.
SUPPLIER	The organization that construct the Stress Joint and provides it under a Purchase Order directly to the PETROBRAS or through the CONTRACTOR for riser EPCI Contract
SUB–SUPPLIER	The Party supplying a material or service to the SUPPLIER.
CONTRACTOR	The company responsible for the engineering, procurement, construction and Installation of riser system for the Project.
PARTIES	The companies directly involved in the Titanium Stress Joint specification, design, fabrication and installation, with power to propose modification over design and manufacturing aspects. They are: PETROBRAS, CONTRACTOR and SUPPLIER.

Cutback	Uncoated area defined in terms of length at the end of the Lower CS Compact Flange or Pup Piece which is required to prevent damage to the coating system when the TSJ is welded together with the pipe sections.
EPCI	Contracting mode where the CONTRACTOR is responsible for the detailed engineering, procurement of some or all the riser components, construction, installation and commissioning of riser system.
Hang–off	Structure that is welded to the porch on the FPU hull and where the Stress Joint will be hung. The Hang–off may be Conical Receptacles or Support–Tubes, and the definition the Hang–off type(s) selected for the Project is given in [2].
Hang–off Adaptor (HOA)	Tubular or thick forged device assembled onto the top of the TSJ, to interface with a Support–tube type Hang–off. Additional requirement in [10].
Monolithic	Refers to a single forged part without welds or other means of permanent connection along the forging.
Project	Scope of activities performed by the PARTIES to design, construct and install the riser system for a specific field and host FPU.
(Conical) Receptacle	Steel casted or forged piece, which interfaces the riser through Stress Joint Adapter Bushing. The standard type of Conical Receptacle, if specified for the Project, is defined in [2].
Requisition	A formal written request for supply of equipment or materials for a specific Project.
(Titanium) Stress Joint	Refers to the entire equipment to be supplied, in its installation configuration. Comprised by an upper steel Transition Spool containing the specified top connection device with the FPU, a steel Adapter Bushing or a Hang–off Adaptor (with or without an attached steel Bushing), a monolithic titanium beam flanged at both ends (through integral Compact Flanges), and a lower integral flange neck (steel) and/ or a riser Pup Piece to matte with the riser pipe (e.g. Figure 1.1 and Figure 1.2).
Support–Tube	Generic term that refers to the tubular type of support that requires a Hang–off Adaptor installed on top of the TSJ to interface with the support, and which can be BSN, BSMF, BSDL, RMoST and TSUDL. The type of Support–Tube, if specified for the Project, is defined in [2].

Work	All tasks to be performed by the SUPPLIER under the Purchase Order for any specific Project, including all duties and obligations undertaken by the SUPPLIER.

Shall	Indicates a mandatory requirement.
Should	Indicates a preferred course of action.
May	Is used where alternatives are equally acceptable.

2.2. ABBREVIATIONS

The following abbreviations are used in this document:

ALS	Accidental Limit State
AUT	Automatic Ultrasonic Test
BSDL	*Diverless Bellmouth (Por.: Boca de Sino "Diverless")*
BSMF	*Multifuctional Bellmouth (Por.: Boca de Sino Multifuncional)*
BSN	*Conventional Bellmouth (Por.: Boca de Sino "Convencional")*
CNC	Computer Numerical Control
CoG	Centre of Gravity
CP	Cathodic Protection
CRA	Corrosion Resistant Alloy
CS	Carbon steel
CTOD	Crack Tip Opening Displacement Test
CVN	Charpy V–Notch
DBM	Design Basis and Methodology
ECA	Engineering Critical Assessment
ELI	Extra Low Interstitials
FAT	Factory Acceptance Test
FEA	Finite Elements Analysis
FJC	Field Joint Coating
FoaK	First of a Kind
FoS	Factor of Safety
FPU	Floating Production Unit. In general meaning herein this specification, it is understood as the larger structure where the hang–off system in attached
GA	General Assembly (Drawing)
HAZ	Heat–Affected Zone
HIC	Hydrogen Induced Crack
HOA	Hang–off Adaptor
HSE	Health, Safety and Environment
ID	Internal Diameter

ITP	Inspection and Test Plan
JIP	Joint Industry Project
L.A.S.T.	Lowest Anticipated Service Temperature
MIP	Manufacturing Inspection Procedure
MPS	Manufacturing Procedure Specification
NCR	Nonconformity Report
NDT(NDE)	Non-destructive Test (Non-destructive Examination)
OD	Outer Diameter
P/N (S/N)	Part Number (Serial Number)
pAUT	Phased Array Ultrasonic Test
PEEQ	Equivalent Plastic Strain
PEP	Project Execution Plan
PO	Purchase Order
PoD	Probability of Detection
~~PPT~~	~~Pre-Production Test~~
PQT	Procedure Qualification Test
PT	Liquid Penetrant Test
QA	Quality Assurance
QC	Quality Control
QHSE	Quality Health, Security and Environment
QTS	Qualification Test Sample
Ra	Arithmetic Average Value of a Filtered Surface Roughness Profile
RMoST	Riser Modular Support Tube
RP	Return Period
Rt	Maximum Height of the Roughness Profile (Range)
SCF	Stress Concentration Factor
S.I.	International System of Units *(Fre.: Système International)*
SMYS	Specified Minimum Yield Stress
SMTS	Specified Minimum tensile Stress
SSC	Sulfide Stress Cracking
SWT	Smith–Watson–Topper Model
TSA	Thermal Sprayed Aluminum
TSJ	Titanium Stress Joint
TSUDL	Diverless Universal Support Tube *(Por.: Tubo Suporte Universal “Diverless”)*
ULS	Ultimate Limit State
UNS	Unified Numbering System
UT	Ultrasonic test
VME	Von Mises Equivalent Stress
WPQT	Welding Procedure Qualification Test

3. REFERENCES

All equipment supplied under the scope of this specification shall be in conformance to the latest editions of the design codes, standards, and PETROBRAS' documents listed hereafter in this section. In addition to these references, Project Specification shall be considered, and shall take precedence with respect to this specification and references cited herein.

3.1. PROJECT DOCUMENTS

Ref. n°	Document number	Title
[1]	--- (1)	Project Technical Specification for Detailed Engineering
[2]	--- (1)	Project Material Requisition/ Design Basis
[3]	--- (1)	Project Material Requirements Specification
[4]	--- (1) (2)	Project Input Data Sheet for Titanium Stress Joint Design
[5]	--- (1)	Project Coating Assessment Specification
[6]	--- (1)	Project Metocean Data
[7]	--- (1)(3)	Project Hang–off Drawing(s)
[8]	--- (1)(3)	Project Support–Tube Mock–up Drawing Guide
[9]	--- (1)(3)	Project Support–Tube Dummy HOA Drawing Guide

(1) Project reference number to be informed within a Project Document List, to be released during bidding phase.

(2) This is the reference for the standard data sheet for Titanium Stress Joint design, with the list of input data, constructed in accordance with main TSJ SUPPLIERS. A PETROBRAS filled version of this standard data sheet, with Project data, will be issued to CONTRACTOR or SUPPLIER during the bidding phase (depending on the chosen purchasing strategy, as per sec. 1.2).

(3) Project selected Hang–off type(s) and specific drawings(s) to be informed during Project bidding phase.

3.2. PETROBRAS'S REFERENCES

Ref. n°	Document number	Title
[10]	I-ET-0000.00-0000-290-P9U-006	Hang–off Adaptor (HOA) Specification
[11]	I-ET-0000.00-0000-274-P9U-001	SLWR Detailed Structural Design Requirements
[12]	I-ET-0000.00-6000-970-PSQ-001	Procedure and Personnel Qualification and Certification
[13]	ET-3000.00-1500-251-PEK-001	Fixadores em Aço Baixa Liga de Alta Resistência para Aplicação Submarina
[14]	ET-3000.00-1500-251-PEK-002	Rastreabilidade de Fixadores de Alta Resistência para Utilização Submarina
[15]	I-DE-0000.00-0000-140-P56-001	Riser Top Connector Mock–up Geometry Reference
[16]	I-ET-0000.00-0000-219-P9U-004	CRA Weld Overlay Clad Pipe Requirements
[17]	I-ET-0000.00-0000-210-PSQ-001	Alternative Flaw Acceptance Criteria of Submarine Rigid Pipeline and Riser Welds

[18]	SwRI Project No. 18.16696	JIP SwRI Final Report. "Fatigue and Fracture Performance Evaluation of Welded Ti 29 Tapered Stress Joints". 2015.

3.3. DET NORSKE VERITAS (DNV)

Ref. n°	Document number	Title
[19]	DNVGL–ST–F101	Submarine Pipelines Systems
[20]	DNVGL–ST–F201	Dynamic Risers
[21]	DNVGL–RP–F108	Assessment of flaws in pipeline and riser girth welds
[22]	DNV–RP–F201	Design of Titanium Risers
[23]	DNVGL-RP-F111	Interference Between Trawl Gear and Pipelines
[24]	DNVGL–RP–C203	Fatigue Strength Analysis of Offshore Steel Structures DnV Recommended Practice
[25]	DNVGL-RP-A203	Technology Qualification
[26]	DNVGL–ST–E271	DNV Standard for Certification No. 2.7-1 Offshore Containers

3.4. AMERICAN PETROLEUM INSTITUTE (API)

Ref. n°	Document number	Title
[27]	API STD 1104	Welding pipelines and related facilities
[28]	API RP 2RD	Design of Risers for Floating Production Systems (FPSs) and Tension-Leg Platforms (TLPs)
[29]	API SPEC 6A	Specification for Wellhead and Christmas Tree Equipment
[30]	API 5L	Specification for Line Pipe

3.5. NATIONAL ASSOCIATION OF CORROSION ENGINEERS (NACE)

Ref. n°	Document number	Title
[31]	ISO 15156-3	Materials for use in H2S-containing environments in oil and gas production – Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys
[32]	NACE TM 01-77	Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H2S Environments

3.6. AMERICAN SOCIETY OF TESTING AND MATERIALS (ASTM)

Ref. n°	Document number	Title
[33]	ASTM A388M	Standard Practice for Ultrasonic Examination of Steel Forgings
[34]	ASTM E1290	Standard Test Method for Crack Tip Opening Displacement (CTOD) Fracture Toughness Measurement

[35]	ASTM E709	Standard Guide for Magnetic Particle Testing
[36]	ASTM E2375	Standard Practice for Ultrasonic Testing of Wrought Products
[37]	ASTM E8	Standard Test Methods for Tension Testing of Metallic Materials
[38]	ASTM B348	Standard Specification for Titanium and Titanium Alloy Bars and Billets
[39]	ASTM B861	Titanium and Titanium Alloy Seamless Pipe
[40]	ASTM B381	Titanium and Titanium Alloy Forgings
[41]	ASTM B499	Standard Test Method for Measurement of Coating Thicknesses by the Magnetic Method: Nonmagnetic Coatings on Magnetic Basis Metals
[42]	ASTM E797	Standard Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method
[43]	ASTM A194	Standard Specification for Carbon Steel, Alloy Steel, and Stainless Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both
[44]	ASTM E1820	Standard Test Method for Measurement of Fracture Toughness
[45]	ASTM G1	Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens
[46]	ASTM E466	Standard Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials
[47]	ASTM E647	Standard Test Method for Measurement of Fatigue Crack Growth Rates
[48]	ASTM E1220	Standard Practice for Visible Penetrant Testing Using Solvent-Removable Process

3.7. AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

Ref. n°	Document number	Title
[49]	ASME Section VIII	ASME Boiler & Pressure Vessel Code, Rules for Construction of Pressure Vessels
[50]	ASME Section V	ASME Boiler & Pressure Vessel Code, Section V: Non-destructive Examination
[51]	ASME Section IX	ASME Boiler & Pressure Vessel Code, Section IX: Welding and Brazing Qualifications

3.8. OTHER STANDARDS

Ref. n°	Document number	Title
[52]	EN ISO 13628-7:2006	Petroleum and natural gas industries — Design and operation of subsea production systems — Part 7: Completion/workover riser systems

[53]	EN 1779	Non-destructive testing. Leak testing. Criteria for method and technique selection
[54]	ISO 13679	Petroleum and Natural Gas Industries – Procedures for Testing Casing and Tubing Connections
[55]	BS 7910	Guide to methods for assessing the acceptability of flaws in metallic structures
[56]	AMS 2380	Approval and Control of Premium-Quality Titanium Alloys
[57]	SAE AMS 2801B	Heat Treatment of Titanium Alloy Parts
[58]	SAE AMS-2750	Pyrometry
[59]	AMS 2645H	Fluorescent Penetrant Inspection
[60]	AMS 3156	Oil, Fluorescent Penetrant, Water Washable
[61]	ISO 17782	Petroleum, petrochemical and natural gas industries — Scheme for conformity assessment of manufacturers of special materials
[62]	ISO 27509	Petroleum and natural gas industries. Compact flanged connections with IX seal ring
[63]	ISO 9712	Non-destructive testing — Qualification and certification of NDT personnel.
[64]	ISO 15549	Non-destructive testing — Eddy current testing — General principles
[65]	ISO 17643	Non-destructive testing of welds — Eddy current examination of welds by complex plane analysis
[66]	ISO 20339	Non-destructive testing — Equipment for eddy current examination — Array probe characteristics and verification.
[67]	NORSOK Standard L–005	Compact Flanged Connections

3.9. CONFLICT OF INFORMATION AND DOCUMENT APPROVAL

In the event of any conflict between this specification or any other specification and associated requisition forms, or with any of the applicable codes and regulations arise, written clarification shall be sought from PETROBRAS before proceeding with the Work. SUPPLIER shall provide PETROBRAS with a written request of clarification. PETROBRAS' decision shall be final regarding interpretation of requirements.

All deviations to this specification and other referenced specifications or attachments listed in this specification shall be made in writing and shall require written approval by PETROBRAS prior to the execution of the Work.

The Stress Joint shall be designed and manufactured in accordance with the regulations applicable for service offshore Brazil.

4. GENERAL REQUIREMENTS

4.1. MATERIAL SUPPLIED

In general terms, it is anticipated that the supplied Titanium Stress Joint will consist of the basic components listed in Table 4.1 (to be confirmed within the contractual documents).

Table 4.1 – Scope of Supply (Breakdown)

Item	Description	Application	Qty per Type
1	**Titanium Stress Joint**	Permanent Equipment	[2], [4]
1.1	Monolithic Titanium Body (UNS R56404 ELI/ UNS R56407 ELI) w\ integral compact flanges in both ends.		
1.2	TSJ Steel Bushing Electrically Isolated from the Ti parts(NOTE 1)		
1.3	Upper Transition Spool (Steel).		
1.4	Lower CS Compact Flange w/ weld prepped neck.		
2	HOA or Adapter Bushing(NOTE 2) (Steel) to Interface with *Hang–off*	Permanent Equipment	[2]
3	Tubular Pup Piece for riser first weld	Permanent Equipment (Optative Item)	[2] (NOTE 3)
4	Mock–up simulating the upper part of the TSJ (Adapter Bushing and Transition Spool), for fit up test on Receptacle and to adjust the FPU closing spool (elevation “A”, Figure 7.1). (NOTE 4)	Construction Accessories (for Receptacles) (Optative Item)	Confirmation of supply and qty. in [2]
5	Mock–up simulating the interface flange with the FPU, for adjustment of the FPU closing spool (elevation “A”, Figure 7.2).(NOTE 4)	Construction Accessories (for Support–Tubes) (Optative Item)	Confirmation of supply and qty. in [2]
6	Dummy HOA Simulating the interfacing region of the HOA with the Support–Tube, for coupling/ assembly verification of this part into the specified Support–Tube of the FPU in the yard (see Figure 7.3).	Construction Accessories (for Support–Tubes) (Optative Item)	Confirmation of supply and qty. in [2]
7	Samples of Lower CS Compact Flange for welding procedure qualification and CTOD(NOTE 5)	Construction Accessories	[2] (NOTE 5)
8	Samples of Lower CS Compact Flange for AUT calibration(NOTE 5)	Construction Accessories	[2] (NOTE 5)
9	Samples of Lower CS Compact Flange for fatigue test(NOTE 5)	Construction Accessories	[2] (NOTE 5)
10	Samples of Lower CS Compact Flange – externally coated pipe for FJC qualification test (NOTE 6)	Construction Accessories	[2] (NOTE 6)
11	Blind flange w/ bolts and nuts or protective cap.	Handling Accessories (Optative Item)	Confirmation of supply and qty. in [2]
12	Handling pull-in/out device w/ seal ring, bolts and nuts	Handling Accessories (Optative Item)	Confirmation of supply and qty. in [2]
13	Gasket rings for final topside spool assembly	Permanent Equipment (Optative Item)	Confirmation of supply and qty. in [2]
14	Studs and nuts for final topside spool assembly	Permanent Equipment (Optative Item)	Confirmation of supply and qty. in [2]
15	Technical assistance (during riser installation)	Onshore Daily Rates	[2](NOTE 7)
16	Technical assistance (during riser installation)	Offshore Daily Rates	[2](NOTE 7)

NOTE 1: Steel bushing with cathodic protection system (anodes), assembled around the static section of the TSJ, to protect the TSJ *Head* and the isolation coating on it from abrasion, and to promote the interface with the receptacle, with or without a separated *Adapter Bushing*.

NOTE 2: Steel bushing with cathodic protection system (anodes), for retrofit into existing conical receptacles. The *Adapter Bushing* should preferably be of closed type and installed together with the TSJ. Open *Adapter Bushing*, with guide plates to align the opening with the receptacle mouth, may also be use. See section 5.3 for more details.

NOTE 3: A steel riser pipe may optionally be provided by CONTRACTOR or PETROBRAS to be factory welded to the *Lower CS Compact Flange* by SUPPLIER.

NOTE 4: Mock–up to be used by FPU constructor for fit up test on the yard during construction. This mock–up shall be provided with a blind flange with the same specification as the *Stress Joint* standard flange per [4] (including N_2 test port if specified). The mock–up shall be able to withstand a leak test for the topside hard pipe, with the same pressure of the riser hydrostatic test (acc. to [4]).

NOTE 5: Welding Procedure Qualification test rings, AUT calibration rings and fatigue test samples shall be manufactured and inspected in forging supplier with the same requirements for the *Lower CS Flange* as defined in sections 8.5, 8.6 and 10. Test rings shall be made from the same batch as the *Lower CS Compact Flange*. If weld overlay is required for the riser, the acceptance criteria for welding qualification test rings shall meet, at least, the requirements defined by the ECA of the first weld. Length and quantity as per [2].

NOTE 6: Test rings for field joint coating (FJC) qualification test. In Projects where the line pipes are supplied by PETROBRAS, it may provide the bare samples, as these rings do not need to be forged (can be extracted from a riser tube). In this case, SUPPLIER shall provide only the coating service for these pieces. Test rings shall be externally coated with the same coating system and end coating cutback characteristic used for Project forged pieces (*Lower CS Compact Flange*). Ring length, quantity and cutback details as per [2].

NOTE 7: In case of direct purchase by PETROBRAS, service daily rates agreed with SUPPLIER shall be included in Purchase Order as optional (not initially summed within the total amount of the PO). In case of EPCI, this requirement will be defined in contractual documents.

4.2. MATERIAL SELECTION

All equipment and material supplied under this Specification shall be new, of proven design, and in accordance with sound engineering fabrication and manufacturing practice. It is preferred to use existing designs or modifications that have been already accepted.

SUPPLIER shall be responsible for the selection of the materials. All materials shall be suitable for the intended service. The selected materials shall be in accordance with the relevant applicable codes, standards and specifications and be able to meet the requirements defined in [2].

The origin and manufacture of all materials used in the manufacture shall be clearly identified. SUPPLIER shall submit any required material manufacturing process details, tests, examinations, inspections, and acceptance criteria for review and approval by PETROBRAS.

SUPPLIER shall select the materials in accordance with the:

- Relevant codes listed in this document and related Project specifications;
- Results of both the structural and the fatigue analysis;
- Maintenance-free requirement during the service life, as per Project specifications;
- Corrosion control;
- Environmental conditions (fluids in contact with TSJ).

The compatibility between all materials shall be checked. Materials shall not be affected by galvanic reactions and can be welded to other specified metallic pieces where necessary. In particular, the adequacy of the compact flange pairs and the nearest steel pipe sections are critical. Requirements can be found in section 7.15 and within Project Specification.

If SUPPLIER intends to consider the weld overlay layer contributing to the strength of the dynamic steel parts (Lower CS Compact Flange and Pup Piece), additional requirements of the DNV Report for JIP Lined and Clad Pipelines, Phase 3 - Design and Construction of Lined and Clad Pipelines [16], and Appendix A.3 of [19], shall be fulfilled.

Additional criteria for weld overlay are presented on section 8.6.

4.3. SUPPLIER'S RESPONSIBILITIES

SUPPLIER shall furnish all labor, consumables, tools, equipment and materials (other than those explicitly identified as supplied by PETROBRAS) required to manufacture, test and deliver the Stress Joint in a safe manner per the agreed schedule. SUPPLIER shall perform all operations required for design, manufacture, inspection, testing, handling and shipping.

Nothing contained in this specification or omitted from it shall be construed as relieving the SUPPLIER of the obligation to supply the Stress Joints in accordance with the functional requirements outlined herein, said to be capable of functioning properly in a riser system for the entire design period specified by PETROBRAS for the Project, without need for replacement of any of its parts.

SUPPLIER shall develop a written Manufacturing Plan/Procedure, which includes a Quality Control Plan, which shall be submitted to PETROBRAS for approval prior to commencement of material procurement and manufacturing.

A pre-production meeting shall be held between PARTIES representatives, plus any third-party inspection personnel involved. The purpose of the meeting is to ensure that all parties involved fully understand job requirements and resolve any outstanding issues prior to commencement of manufacturing.

PETROBRAS furnished drawings and specifications shall be checked by SUPPLIER immediately upon receipt, and SUPPLIER shall promptly notify PETROBRAS of any discrepancies therein.

For any requirement in question by SUPPLIER, it shall be SUPPLIER's responsibility to:

- Obtain clarification from PETROBRAS, which shall be final and binding;
- Review and resolve conflicts with PETROBRAS prior to initiation of Work or continuation of Work.

SUPPLIER shall allow PETROBRAS reasonable access to all areas concerned with design, manufacture, inspection and testing during all times while Work is being performed for this order.

SUPPLIER shall provide all reasonable facilities to PETROBRAS inspectors, without charge, to satisfy the inspector that product is manufactured in accordance with this Specification. Such facilities shall include, but not limited to, office equipment and telecommunication equipment. CONTRACTOR shall perform a complete visual inspection at the place of manufacture prior to shipment, and upon the receipt of the TSJ at the construction site. If any inspection or testing reveals details not in accordance with this Specification, then SUPPLIER may demonstrate to PETROBRAS that the product still satisfies the design requirement. If SUPPLIER is unable to demonstrate this to PETROBRAS's satisfaction, then the manufacturing and/or testing procedure shall be repeated until compliance is demonstrated. All such remedial work shall be performed at SUPPLIER's cost.

SUPPLIER shall furnish all data generated during the design cycle of the Titanium Stress Joint including the results of the numerical analyses that will be carried out in order to fulfill the design requirements. This documentation shall be comprised of written report, in a layout defined by the PETROBRAS, and the electronic input and output files of the finite element and ECA analysis.

Equipment used for the manufacture shall be of proven design and in good operating condition.

Methods employed shall be in accordance with prudent engineering, fabrication and construction practice.

All costs including taxes are to the SUPPLIER account in undertaking the responsibilities.

Deviations from this Specification are not permitted. All proposed changes or modifications to this Specification shall be submitted in writing for PETROBRAS approval. Approved changes shall be incorporated into a revised, approved purchase specification. Disclaimers are not permitted.

4.4. PRODUCT QUALIFICATION

SUPPLIER shall demonstrate the qualification of the product for the intended service. Refer to section 12 for TSJ qualification requirements.

4.5. UNIT OF MEASUREMENTS

All data shall be reported in primary S.I. units; however, customary US units may also be reported for reference only.

5. FUNCTIONAL REQUIREMENT

5.1. TSJ ASSEMBLY

- The TSJ shall be design and sized in a way to guarantee that its titanium portion (Head and Extension) will be a monolithic piece. Weld on titanium parts shall be avoid;
- The TSJ assembly shall provide a secure attachment of the riser to the hull under all specified load conditions;
- The TSJ assembly shall fit together so that under load there is no relative movement between mating parts;
- The TSJ assembly shall transfer all specified load conditions without gross yielding, buckling or failing during the specified service life;
- During a catastrophic event, the TSJ assembly design shall provide that failure is likely to occur in the riser pipe rather than the TSJ assembly or hull structure;
- The TSJ assembly shall be designed to withstand a constant hydrostatic pressure at specified installation maximum water depth, including pre-abandonment if required, for a minimum of twelve (12) months;
- The TSJ assembly shall be electrically conductive between the platform piping and riser;
- The TSJ assembly shall provide an electrically isolating barrier between the riser and the FPU hull, preventing the riser CP from draining into the hull structure;
- The TSJ assembly, mainly in the interface with dissimilar metallic parts, shall be protected from galvanic potential to prevent the formation of hydrides. Especially attention shall be taken at the Compact Flanges connections, where;
- The TSJ flanges shall maintain a leak tight connection under all specified load conditions using a metal ~~IX or~~ [EXCLUDED] HX seal ring as the primary pressure barrier;
- The TSJ flanges shall provide a fatigue resistant, quasi-static connection, mostly isolating the bolts of dynamic loadings as defined in sec. 5.4;
- The TSJ flanges shall be designed to avoid yielding of the titanium material for all combinations of make-up and operational loads;
- The TSJ upper flange mating to platform piping shall be designed to carry riser installation loads.

5.2. EXTERNAL COATINGS

External coatings shall be used on 100% of the exposed surface of titanium parts to afford complete electrical isolation of titanium parts from the electrolyte, and galvanic shielding from steel components to which the Stress Joint is connected in service.

SUPPLIER shall comply with the requirements for the external coating and tests (PQT, pre-production and production phases) of titanium and steel parts presented in [5].

For risers with maximum operating temperature closer to the selected material limit, a thermal analysis, as instructed in section 7.8, shall be done to determine the temperature profile through the polymeric coating thickness to be compared with the material qualified limit.

If conical receptacles are specified for the Project, a (temporary) anti-impact, anti-abrasion coating, as for example polymer shells, shall be applied leastwise on 3 meters from the top of the *Extension* (dynamic section) to mitigate the risk of indentation or impact on the *Stress Joint* surface during installation. Typically, this temporally protection shall attend an impact test of 10kJ in accordance with [23] (hammer of 50mm diameter) and shall be easily removable by divers after installation.

The primary rubber isolation coating shall be completely accessible for visual inspection after installation.

5.3. STEEL BUSHING AND ADAPTER BUSHING

- The *Steel Bushing/Adapter Bushing* shall provide a secure attachment of the TSJ assembly to the hull under all specified load conditions.
- The *Steel Bushing/Adapter Bushing* and TSJ Assembly shall fit together so that under load there is no relative movement between mating parts.
- The *Steel Bushing/Adapter Bushing* shall be designed to fit inside the Project Selected *Hang–off*. *Receptacle* and *Support–Tube* dimensions and tolerances shall define the fit and clearance of the *Steel Bushing/Adapter Bushing*, according to the requirements of section 7.2 and from [8], [9] and [15].
- The *Steel Bushing/Adapter Bushing* shall transfer all specified load conditions without gross yielding, buckling or failing during the specified service life.
- During extreme and accidental events, the *Steel Bushing/ Adapter Bushing* shall provide that failure is likely to occur in the riser pipe (or in the HOA) rather than the TSJ assembly or hull structure.

For *Conical Receptacle* type *Hang–off*:

- The base case *Adapter Bushing* configuration should be of closed type, to be supplied assembled on the TSJ *Head*. Reasonable lateral mass reduction on the external profile is encouraged, for as much as it does not harm the contact with the two lateral regions of contact with the *Receptacle* (e.g. due to excessive deformation, beyond gap tolerance) and pass the local analyzes criteria.

- Opened type *Adapter Bushing* may be used, since supplied assembled on the TSJ *Head* and counting with guide plates to align the opening with the receptacle mouth. The use of drop–in (opened) *Adapter Bushing* separated from the TSJ, if intended by CONTRACTOR, shall be first approved by PETROBRAS.

- Corrections of riser top angle and/ or azimuth with respect to *Receptacle* angles using the *Adapter Bushing* is not permitted. CONTRACTOR shall consider this requirement when choosing the nominal riser top angles, because such angular offsets from receptacle centerline, and the consequent permanent (static) deflection of the TSJ dynamic section, could increase the interface load and stresses for high angles variation scenarios (e.g. survival load cases).
- A solid numeric model of the designed *Adapter Bushing*, the *Steel Bushing* and the portion of the TSJ *Head* within it shall be provided to PETROBRAS to assist in evaluating FPSO porch structure.

For *Support–Tube* type *Hang–offs*, the requirement for HOA design in [10] shall be observed.

5.4. COMPACT FLANGES

- SUPPLIER shall provide the data sheet of the selected compact flanges, as per [67], for the interfaces with the FPU spool and with the riser. Information shall include commercial\standard designation (or detailed drawing for modified designs), material and qualified loads envelope capacity. Seal ring type shall be type HX.
- Integral compact flange shall be sized per strength capacity calculation of annex A of [62]. SUPPLIER should use the maximum tension, associated with the design pressure, that leads to 100% of the pipe capacity (1.0VME), per [54]. This is a conservative approach for flange design instead of using the final Project calculated loads and load cases. Very limited plastic strain (PEEQ) may occur at titanium and steel compact flanges per local failure criteria from annex D2.4 of [52] and, in this case, SUPPLIER shall submit a request to PETROBRAS for approval.
- The functionality of the seal for the workloads shall be checked up to the pipe capacity (1.0VME), and shall guarantee the average contact pressure at primary sealing area to be at least two times the flange pressure rating per [52] annex H.4.
- The TSJ flanges shall provide a fatigue resistant connection by limiting the increase of bolt nominal stress in no more than 5% as defined in [62], due to the riser dynamic loadings. The 95% balance of the bolt stress shall be carried in the pre-loaded flange faces.

- Thicker wall at the top of the *Steel Compact Flange* neck, associated with a longer, tapered section neck should be considered, if large loading (extreme and fatigue) is applied in this part. Especially if such loads put the TSJ close to SUPPLIER's monolithic *Stress Joint* length limit.
- At least FEA half–models of the *Compact Flange* shall be employed, to capture bending behavior.
- High strength steel studs, or other material, may be considered for lower stress fatigue non–critical flanges (e.g. *Transition Spool's* compact flange), upon PETROBRAS approval.
- Compact Flange assembly, torquing and pre-loading procedure shall be prepared and submitted to PETROBRAS review.

6. MATERIAL REQUIREMENTS

Table 6.1 provides the TSJ material requirements by component. Alternative materials or modifications to industry specification shall be reviewed and approved by PETROBRAS, as per requirements of sec. 6.1.

Table 6.1 – TSJ Component Material Requirements.

Component	Material	Code(1)	SMYS	Notes(2)
TSJ Main Body	Titanium	ASTM-B381-Gr29 ASTM-B381-Gr23(3)	758 MPa 758 MPa	Used for NACE Used for Non-NACE and ≤ 70°C
Steel Compact Flanges	Steel forging	ASTM-A707- L5	≥450MPa	Acceptable material/ grade.(1) Inlay of CRA may be considered, as per section 7.15.
Steel Transition Spool	Steel forging	ASTM-A707- L5	≥450MPa	Acceptable material/ grade.(1)(5) Inlay of CRA may be considered, as per section 7.15.
	(Steel Pipe)(5)	Ref. [3]		
Hang-Off Collar	Steel forging	ASTM-A694 ASTM-A707-L5 ASTM-A707-Gr1	≥450MPa ≥450MPa ≥552 MPa	Acceptable materials/ grades.(1) Inlay of CRA may be considered, as per section 7.15.
TSJ Bushing	Steel forging	ASTM-A707-L5	≥450MPa	Acceptable material/ grade.(1)
Adapter Bushing	Steel forging	ASTM-A707-L5 ASTM-A707-L5 ASTM-A707-Gr1	≥345 MPa ≥448 MPa ≥552 MPa	Acceptable materials/ grades(1)
TSJ Studs & Nuts	Titanium	ASTM-B381-Gr29/23	793 MPa	Property after heat treatment. Other material\ grades may be proposed for PETROBRAS approval.
Tie-In Spool Studs(4)	Steel	ASTM-A193-GrB7	724 MPa	---
Tie-In Spool Nuts(4)	Steel	ASTM-A194-Gr2H	1205 MPa	Proof Load per [43]
Flange Seal Ring	Nickel	ASTM-B564	414 MPa	Alloy UNS N06625, Xylan coated

(1) Any modifications to industry specification shall be submitted to PETROBRAS prior the manufacture.
(2) According to SUPPLIER specification. Calculation notes shall demonstrate the adequacy of the choice.
(3) Non-NACE material application in accordance with the Project requirement, [4].
(4) Studs and nuts shall comply also with PETROBRAS specification of [13] and [14].
(5) Integral forged piece as base case. However, combination of welded forgings (extremities) and pipe may be considered. Acceptable pipe specifications per [3].

6.1. MATERIAL SELECTION

The compatibility between all materials shall be checked. Galvanic compatibility is required for all dissimilar material interfaces. In particular, the compatibility between the flanged connections (including fasteners and gasket) of the riser and FPU pipes and the Titanium Stress Joint are critical. A galvanic compatibility assessment of all TSJ components shall be included within Design Report.

NOTE: compatibility of the internal parts shall also be checked. Design shall avoid any harmful contact between dissimilar material (including bushing, transition spool, compact flange, bolts, studs and nuts).

SUPPLIER shall also perform and report a chemical compatibility assessment, as per section 9.5, of the selected TSJ materials in contact with the riser conveyed fluids and injected chemicals from the information provided by PETROBRAS in the data sheet of [4]. SUPPLIER shall also report, for information, a list of fluids\ concentrations harmful to the integrity of TSJ (to be avoid), even if not listed in the data sheet, according to previous experience and qualifications.

SUPPLIER shall be responsible for the selection of the riser *Stress Joint* materials, which shall be approved for sour service per [31], if so specified in [4]. All selected materials shall be suitable for service under specified internal conditions (pressure, temperature, fluid/solids composition, flow rates, etc.) and external environmental conditions as defined in this specification and any clarifications provided by PETROBRAS. Accepted titanium materials and grades are ASTM-B381-Gr. F29 ELI (UNS R56404) for sour service per [31], if so specified in [4], and ASTM-B381-Gr. F23 ELI (UNS R56407) for “sweet service”, per Table 6.1. In case SUPPLIER propose other titanium alloys/grades, all the qualification tests a) to k) of section 12.1.1 for such alloy shall be completed prior to the start of Work.

SUPPLIER shall detail all component materials in SUPPLIER’s submission for PETROBRAS’s review. SUPPLIER shall also submit any required material manufacturing process details, tests, examinations, inspections and acceptance criteria for each selected material to the PETROBRAS for review and approval prior to purchase of materials. Materials specifications shall include fabrication techniques, chemical composition, target chemistry with allowable chemistry ranges, fracture toughness, forging/sizing procedures. The chemical composition specification and material properties selected shall be approved by PETROBRAS. PETROBRAS shall also approve all material selection and fabrication SUB-SUPPLIER and fabrication facilities for the seamless tubular or forgings to be used for the Stress Joints. The criteria of material SUB-SUPPLIER conformity of [61] shall also be observed for material selection.

Titanium forging, fasteners, and components shall be produced by the sponge refining technique or alternate high-quality process to minimize hydrogen and interstitial elements such as carbon, oxygen, nitrogen and iron to produce an extra low interstitial (ELI) grade. Processing standard shall conform to [40] Grade F23 or F29 (forgings). Requirements from [39] (seamless pipe), and [38] (bar and billets) may also be considered, subjected to PETROBRAS approval in each case. Requirements of macrographs as per [56] shall also be regarded.

NOTE: Grade F23 may be used if sweet service is stated within the [2] and [4], and when the design or incidental temperature is under 70°C. SUPPLIER shall demonstrate the adequacy of all selected material for the intended use due to other characteristics of Project's fluid (e.g. brine, ppCO2, injected chemicals, etc.).

Copies of material specifications, results of all mechanical properties tests, and mill test certificates shall be provided to PETROBRAS. Material, which is not traceable, shall not be used.

Repair welding by the heavy-wall seamless-tubular product or forging SUB-SUPPLIER is not allowed.

7. DESIGN REQUIREMENT

7.1. GENERAL

SUPPLIER shall design and construct the TSJ to accommodate the specified values for angular rotation, axial loads, temperatures, and pressures for the specified service life within allowable stress limits specified in [28]. PETROBRAS will provide the riser design basis covering the entire riser system including the TSJ, as per Section 3.1.

The design requirements applicable to the Stress Joint shall include, but not be limited to the following:

- The TSJ design shall conform to the chemistry of fluids passing through the risers. The Stress Joint shall be designed for sour service per [31] requirements, if sour service is expected as per [2].
- Titanium studs of the Compact Flanges shall be electrically isolated from the flange (Ti and CS), for instance by mean of ceramic coating applied on the face of the nuts in contact with the flanges, and dielectric material installed in the holes in the annular space between the studs and the flange. If high strength steel studs are approved to be used, then electrical contact with the CS side of the flange shall be guaranteed, as per section 7.15.
- The TSJ shall transfer all loads at their maximum design limits without gross yielding, buckling, collapsing, or failing during the specified service life.
- The Stress Joint lower connection Pup Piece shall be designed to be compatible with the riser pipe, both in term of material and dimension.
- The TSJ shall be designed to interface with the Project selected *Hang–off*, per [4], considering the prescribed gaps and tolerances in [7] to [9] and [15], and the expansion of the Adapter Bushing due to the Head/ HOA settlement in it, if any.

- The TSJ shall accommodate the riser cyclic load without failure for a fatigue life greater than the Project service life factored by 10. The combined fatigue life will include contributions due to installation and wave induced fatigue. SUPPLIER shall get approval from PETROBRAS regarding parameters, techniques, and programs used for the FEA and fatigue analysis prior to starting either FEA or fatigue analysis.
- The fabrication of the Stress Joint shall be subject to inspection, verification, qualification, and documentation in accordance with PETROBRAS's and industry standards.
- The Stress Joint shall successfully pass the factory acceptance testing (FAT), as well as dimensional and visual inspections as per section 11. Tests specification and criteria shall be submitted to PETROBRAS comment prior to the stars of FAT.
- SUPPLIER shall submit a complete Design Report and drawings (as per sec. 13.4) to PETROBRAS for review and approval.

7.2. DIMENSIONS

The *Stress Joints* shall match with the dimensions of the Project selected receptacle(s), with the annular gap prescribed in [15]. Fabrication tolerances of the external profile of the TSJ (Adapter Bushing) and contacting areas of the receptacles including coatings shall be considered, as well as the calculated lateral expansion due to the riser tension. Interference/assembly study shall be performed.

NOTE: If the calculated expansion of the *Adapted Bushing* outer diameter caused by the settlement of the Head/ HOA due to riser tension, added to the other fabrication tolerances, is expected to exceed the nominal tolerance of the annular gap, a re-design of the external profile of the *Adapter Bushing*/ HOA shall be carried out.

The design of the *Stress Joint* shall assure free rotation of the lower *Extension* (without contact with the Body or the *Receptacle*) over the maximum Project specified angular deflection. *Hang–off* mounting angle tolerance, as per [4], shall be considered.

TSJ's riser end dimension and tolerances shall be considered in view of welding requirements (Hi-Lo), and coating requirements (coating cutback characteristic).

In case standard flange is specified, the specified flange elevation "A" above *Receptacle* bottom to the top connection (along TSJ centerline), or above the top of the *Support–Tube*, and the minimum required clearance "B" beneath the flange, for subsea flange assembly, are given in [2] and [4] for each TSJ type (see Figure 7.1 for *Receptacle* and Figure 7.2 for *Support–Tube* type *Hang–offs*). SUPPLIER/ CONTRACTOR shall consider these values on the TSJ design, and inform PETROBRAS, during clarifications in bidding phase, if this requirement cannot be fulfilled.

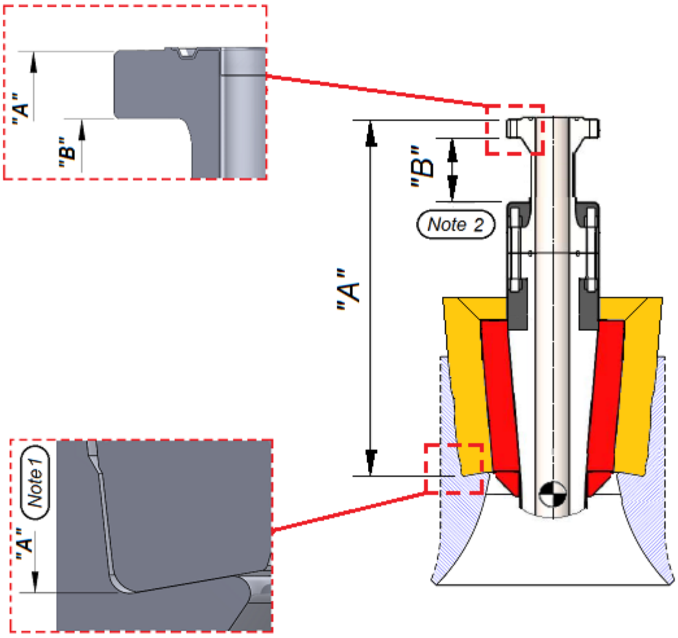

Figure 7.1 – Flange elevation "A" above Receptacle/ Adapter Bushing bottom, and minimum clearance "B" for subsea flange assembly/ disassembly.

NOTE 1: [Figure 7.1] the reference bottom edge for elevation "A" is the *Receptacle* lowest edge. The actual height of the TSJ shall take into account the Adapter Bushing dimensional tolerances, the calculated settlement of the TSJ due to riser tension, and the lateral gaps between TSJ/ *Adapter Bushing* and the receptacle.

NOTE 2: [Figure 7.1] the reference bottom level for minimum clearance "B" shall take into account the nearest obstruction below the bolt hole, considering a region within 3 times the flange bolt diameter about whole centerline.

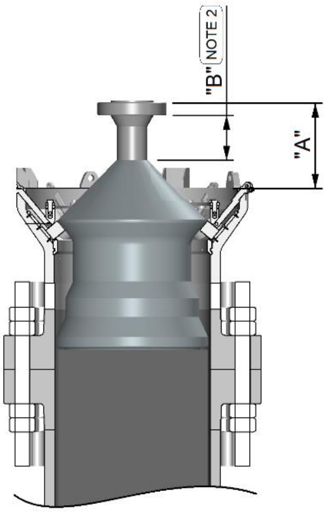

Figure 7.2 – Flange elevation "A" above the top of the *Support–Tube*, and minimum clearance "B" for subsea flange assembly/ disassembly (Mock-up).

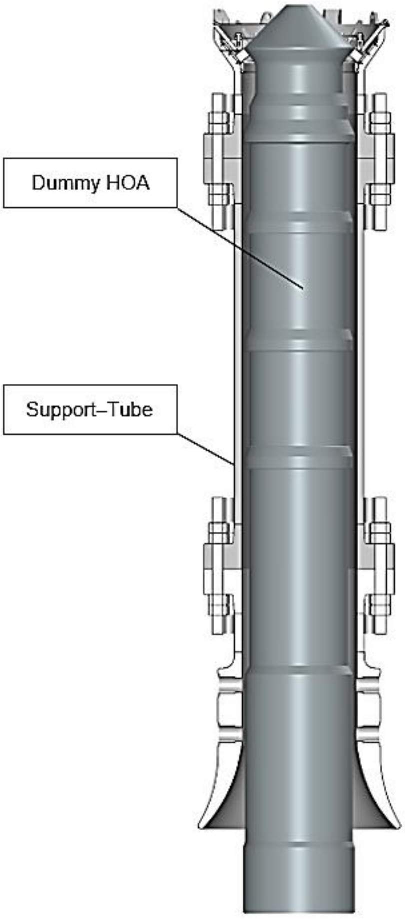

Figure 7.3 – Schematic View of the Dummy HOA for Coupling/ Assembly Verification.

For weld neck or connector, elevation to neck end or to the connector sealing face is defined in [4].

In case mock–up and dummy devices are required for the Project, then CONTRACTOR shall consider the drawing of [15], with mock–up for Receptacle reference geometry, and/or [8] and [9], to guide the construction of these devices.

In case different internal diameters are specified for the riser bore and for the top connection spool (FPU interface) in [4], a smooth 1 : 5 slope diameter transition shall be provided, in the *Transition Spool*.

7.3. DESIGN LOADS

From the global riser analysis and environmental conditions, PETROBRAS or CONTRACTOR will provide the riser interface loads at the Stress Joint termination locations, including maximum tension, maximum bending moment (or bending angle with respect to the center of rotation in the hang-off), and fatigue tension/ angle histograms, as required.

SUPPLIER then shall size the TSJ according to the load cases provided by PETROBRAS or CONTRACTOR and return with the size and critical section locations along the TSJ (taper transition), so the abovementioned histograms can be correctly informed. SUPPLIER shall provide also the interface load (i.e. reacting moment on the *Hang–off*), and the TSJ *Steel Bushing* (if any) and *Adapter Bushing*/HOA geometry, as 3D CAD model, and the exact position of the point of application of forces to PETROBRAS to subsidize the design of the *Hang–off* design.

7.4. LOADING CASES

Table 7.1 indicates the minimum set of design cases to be considered in the structural design of titanium and steel parts from each Stress Joint type for the Project. [4] summarizes all these load cases. The responsibilities about the emission of the final data set for TSJ design is presented on section 1.2. The complete set of load combinations for riser global analysis is listed in [11].

Table 7.1 – Design Loading Case Matrix for Stress Joint.

Design Case	Load Category	Description	Load Combination from Riser Global Analysis, [11]	Design Loads	Cf (1) [28]
1	Temporary 1	Hydrotest	ULS1	[4]	1.35
2	Maximum Operating	10 years return period storm	ULS3		1.0
3	Extreme 1	100 years return period storm	ULS2		1.2
4	Extreme 2	1 year RP. Incidental Pressure	ULS4		1.2
5	Extreme 3	10 year RP. One mooring line broken(2)	ALS2		1.2
6	Survival 1	100 year RP. One mooring line broken(2)	ALS1		1.5
7	Survival 2	1 year RP. Flooded Hull Compartment(3)	ALS3		1.5
8	Temporary 2	Installation(4)	-		1.2
9	Abnormal 1	10 years-RP, with loss of buoyance modules	ALS6		1.2
10	Abnormal 2	100 years-RP, with loss of buoyance modules	ALS5		1.2
11	Fatigue (Sec. 7.7)	Fatigue conditions (wave with associated annual current distribution)	-		N/A

(1) The Cf factor is the design case factor used to calculate allowable stresses, as per [28]. Load categorization may vary depending on chosen design code.
(2) Load category to account for the maximum FPU drift.
(3) Load category to account for the maximum accidental top angle.
(4) Installation cases to be defined by CONTRACTOR, following also the provisions of section 7.13. Max. allowable installation water depth according to [4].

The selection of load cases to be analysed, for the design case 1 to 4 of Table 7.1, shall be performed in accordance with section 7.1 of [11]. One plot of “Tension x bending moment” shall be presented for each load category of Table 7.1 and shall include all results from global analysis and the selected load cases in order to demonstrate that the selected ones are representative of the whole set of results. At least the load cases with the maximum resultant bending moment and the maximum tension values shall be selected (with the respective associated tension and angle values).

Additional load case(s) other than those cases listed in Table 7.1 may be included, to account for any specificities of a given Project. Any Project extra load case condition will also be clearly defined within Project documentation in [2] and [4].

The mounting angle tolerance of the receptacle at the FPU, defined in [4], shall be considered as an additional permanent deflection of the TSJ, and shall be considered in a conservative form.

Any difference from riser angles and the TSJ mounting angles shall be included by CONTRACTOR in global analysis models.

Appropriate fluid combination (pressure and temperature), as per flow profiles informed within [2], shall be considered in each load category of Table 7.1. More than one combination should apply, and SUPPLIER shall evaluate the most relevant combinations according to its design methodology.

7.4.1. Interface Loads

Any relevant interface loads due to top flange connection (FPU spool or attached equipment if any), provided by PETROBRAS in ref. [2] and ref. [4], shall be used as input data for structural design of Stress Joint.

Beside the loads, SUPPLIER shall perform local analysis of the interface between the Adapter Bushing and the Project selected standard receptacle, with appropriate friction coefficient on the contacting areas and the annular gap specified in section 7.2. Eventual tilting angle of the TSJ axis with respect to the receptacle axis, if it happens, for example during extreme or accidental events (survival load case), shall be reported. Especially the load cases which induce the highest bending moment and the lowest riser tension (with associated tension and bending moment respectively) shall be verified.

Information of the actual receptacle and box structure complete dimension, as well as confirmation of the analyses criteria used for porch design, could be provided by PETROBRAS if demanded by SUPPLIER, to assist SUPPLIER in the TSJ design. Likewise, information on the closing spool to be used be SUPPLIER in the model. SUPPLIER is not responsible for receptacle, porch structure and closing spool design.

7.5. DESIGN CRITERIA

TSJs typically have D/t ratios below 10 as well as concentrated stresses in locations along the taper. The use of elastic stress analysis and stress classification per [28] to demonstrate structural integrity can produce non-conservative results in these sections. A complete finite element analysis shall be made of all components that contribute to TSJ strength capacity and sealing capability.

Annex D of [52] provides guidelines for finite element analysis and establishes TSJ design criteria for both elastic and elastic-plastic stress analysis for steel parts. Plastic deformation on titanium parts shall not be considered.

In addition to comparing the TSJ stresses to the allowable criteria for the riser design load cases, it may also useful to compare riser limit loads to the ultimate capacity of the hang-off system to ensure a systematic and controlled failure sequence during a catastrophic event. For example, during a catastrophic event the riser should be designed to fail before the *Hang-off* system or hull structure reach ultimate capacity. The design of riser hang-off structures is not specifically covered by current industry codes. However, the ultimate capacity methodology given in [52] Annex D may be applied. For example, ultimate capacity of the *Adapter Bushing for Receptacles* may be defined as any of the following (derived from guidelines in [52] Annex D.2.4):

- Principle strain exceeds 2% across entire primary structural section;
- Equivalent plastic strain exceeds 10% or $0.5x\left(1-\frac{\sigma_y}{\sigma_u}\right)$ at any point in the structural section;
- Global structural instability, excessive receptacle deformation or plastic collapse is reached.

Design criteria for the HOA are listed within [10].

7.6. FATIGUE REQUIREMENTS

- SUPPLIER shall furnish the TSJ stress concentration factors to be applied in the riser global model, with the respective calculation sheets.
- SUPPLIER shall submit to PETROBRAS the intended criteria to be used for fatigue analysis (fatigue curves) for titanium and steel parts.
- Supplier pre–qualified titanium fatigue design curves may be used, following PETROBRAS review and approval as per section 12. In case SUPPLIER design titanium S–N curve is not present or not approved for use in the Project, the base case curve from the JIP [18] shall be employed, valid for both sweet\ sour service, internal\ external fiber and base metal ~~\weld~~ [EXCLUDED] section, and for grade 23 and 29. Such curve is defined by $N \times \Delta\sigma^6 = 2.87 \times 10^{19}$ (with Δσ in MPa), and was raised with constant load amplitude at R = 0.1.
- Lower weld S–N curves in air from [24] may be used, if possible given the stress levels, seeking to make UT inspections more feasible.
- The design S–N fatigue life calculated for the TSJ shall exceed the specified Project service life factored by a FoS of 10.
- Storm waves contribution on TSJ and riser welds fatigue life shall be included within the fatigue analyses. The most damaging extreme waves at the Top of Taper section, for each return period, shall be selected and included among the operational fatigue waves, as per section 7.1.2 of [11].

7.7. FATIGUE ANALYSIS

CONTRACTOR shall determine fatigue life and generate stress histograms for the critical sections along the TSJ. These sections are project specific and shall be defined on the project's TSJ general arrangement drawings. These reference sections shall be located at the top of taper, the start of taper, the Ti Compact Flange and steel weld sections. The corresponding SCF on the outer surface shall be calculated by FEA for each of these sections.

NOTE: During bidding phase of EPCI contracts, PETROBRAS may provide stress histograms based on Basic Design analysis, in the format and for assumed critical section positions given in the standard data sheet in [4]. These histograms consider wave-wind-current combination at Project location and may include "storm conditions" and extreme current events, to subsidize preliminary assessment. SUPPLIER may use these histograms and positions as references to interpolate the static and cyclic stresses to the corresponding TSJ geometry to be pre-dimensioned for the Project. The responsibility for the emission of final fatigue data is according section 1.2.

For critical, non-welded sections of the TSJ, without significant residual stresses, SUPPLIER may propose a method for compensate for the stress ratio variation (R–ratio) along the sections, as per sec. 2.5 of [24], the SWT method or other. Stress reduction method shall not be employed for cold formed tubular sections with residual tensile stresses due to the fabrication process. The method, along with any detailed material (empirical) fatigue parameters, coefficients and exponents used shall be submitted to PETROBRAS approval.

7.8. THERMAL ANALYSIS

The thermal analysis to determine the temperature at the Isolation rubber coating shall take into account the appropriate fluid combination (pressure and temperature), as per flow profiles informed within [2], per each Load Category of Table 7.1.

The seawater temperature shall be given by [6], considering i) for extreme analyses, the maximum seawater temperature (Tmax) at the level corresponding to the minimum water depth at TSJ position and ii) for long term analyses (if required), the average seawater temperature (Tavg) at the level corresponding to the mean water depth at TSJ position. Linear interpolation may be used.

Thermal properties of the conveyed fluid of ref. [2] shall be used.

7.9. ECA REQUIREMENTS

SUPPLIER shall perform a fatigue assessment based on fatigue crack growth calculations so that maximum initial defect height size left after fabrication and non-destructive testing would not grow to a critical size during service life. A ECA procedure shall be elaborated according to [17], [20], [21], [28] and [55] and submitted to PETROBRAS for approval. The target life for the fracture mechanics evaluation of TSJs shall be the design service life, as per [2], factored by:

- a DFF_{ECA} of 5 where the assumed initial defect can be reliably derived from PoD 90%|95% and sizing error of the NDT in place according to [17] and [19];
- a DFF_{ECA} of 10 where the assumed initial defect is the expected value of defects (mean) according to [20] and there is limited practical trials on NDT reliability.

Maximum initial defect height sizes depend on flaw length. Detected flaws shall be evaluated considering NDT acceptance criteria and sizing error. Non detected flaws shall be evaluated considering NDT capabilities with a postulated full-circumferential flaw. SUPPLIER shall inform the critical sections where the tension-angle histograms should be informed. Both static and cyclic loading information from the riser global analyst will be provided by PETROBRAS. Tension-angle histograms will be generated with enough fine blocks (bin size) at small values of tension and angle. SUPPLIER shall generate by each section the stress blocks derived from the histograms to be provided by PETROBRAS within [2] and data sheet [4].

7.10. MAINTENANCE

The Stress joint shall not require any intervention for maintenance or repair during the specified service life. However, the riser shall be removable and re–installable. The *Stress Joint* shall meet this requirement and PARTIES shall work together to generate a procedure for such operation, per sec. 13.3.

SUPPLIER shall provide an inspection and repair procedure for the external elastomeric cover (dry and underwater).

The Stress Joint shall be capable of passing inspection pig as per section 7.12.2.

7.11. IN-SERVICE INSPECTION

PARTIES shall work together to generate an Inspection and Maintenance Manual (sec. 13.3) for the periodic inspection confirming the integrity of the Stress Joint and the related components during the service life of the field.

7.12. PIGGING REQUIREMENTS

Stress Joint design shall consider following requirements related to pigging:

- Enable riser cleaning with foam-pigs, brush pigs and magnet-pigs in order to remove residues, according to pre-commissioning procedure;
- Enable riser gauging, consisting of the passage of a bi-directional calliper or pig with gauging plate, as defined in design;
- Enable pigging operations in two directions;
- Internal diameter transitions may be required by PETROBRAS and will be defined in Contractual Documents. In this case, the provisions of section 7.2 shall be considered.

- The *Stress Joint* shall neither be damaged nor loose its sealing properties because of the pig passage.

NOTE: The TSJ itself will not be subjected to internal inspection with pig but is required to allow unimpeded passage of the various types of pig as stated above. The in-service pig launcher/ receiver will be installed on the top side of the FPU, therefore no disassembly of spool on the TSJ side will be required.

7.12.1. Conventional Pig

The Stress Joint shall be capable of passing disc-type (Mandrel / Solidcast) pigs equipped with wire brushes. SUPPLIER shall review the Stress Joint design based on the overall design criteria and demonstrate to PETROBRAS's satisfaction that this can be achieved.

SUPPLIER's evaluation shall consider the dimension, material and operation of typical disc-type pigs and the minimum pig length required for the pig to pass through the Stress Joint without losing its seal.

7.12.2. Inspection Pig

The Stress Joint shall be capable of passing inspection pigs (ultrasonic or magnetic type inspection pig for CS riser inspection) in both directions.

7.13. INSTALLATION

SUPPLIER shall assist PETROBRAS during preparation of the Stress Joint installation and handling procedure. SUPPLIER shall review CONTRACTOR's installation and handling procedures.

The selected Installation method (S–, J– or reel–lay), and operational limitation, if any, will be informed by PETROBRAS within Project documentation. SUPPLIER shall inform if additional equipment (e.g. protective shrouds) will be required. PETROBRAS will arrange with the PARTIES a review of the Installation Procedures as they relate to the TSJ.

PETROBRAS, or CONTRACTOR directly, will supply all relevant details of the installation plans and requirements to SUPPLIER for review and comment regarding suitability for use with Stress Joint operational parameters. These details may include the following:

- General installation procedures;
- Commissioning details for the *Stress Joint* and riser;
- Pre-commissioning pig receiver dimensions;
- Special tool requirements and transfer/ pull in rigging characteristic for installation;
- Requirement for *Stress Joint* mock-up (optional).

7.14. CONNECTION AND WELDING

The attachment of the riser to the TSJ *Extension* (*Lower CS Compact Flange* or steel *Pup Piece* if any) shall be a butt weld connection (CONTRACTOR scope). SUPPLIER shall assure that the TSJ termination's material and dimensions, including any internal CRA layer and external coating, are compatible with the mating riser components in accordance with the Project Requisition [2].

SUPPLIER shall support weld qualification of the interface weld between the *Lower CS Compact Flange* and the *Pup Piece* or the riser pipe by providing material certificates and material samples of the forged steel Compact Flange, if *Pup Piece* is not included within SUPPLIER scope as per [2]. Additional weld requirement of [1] and related documents shall be observed.

NOTE: SUPPLIER shall not be responsible for performing the weld between the TSJ termination (*Lower CS Compact Flange* neck or *Pup piece*) and the riser pipe.

NOTE: The weld test rings should be supplied as prolongation of the same forging of the *Lower CS Compact Flange*, but it may be supplied from a separate forging, provided that the forging material is from the same heat, undergoing the same manufacturing process, and heat-treated together with the steel *Compact Flange*.

7.15. STEEL PARTS CORROSION PROTECTION

Corrosion protection of the *Stress Joint* and the riser shall be accomplished with a combination of a protective coating and cathodic protection.

The *Pup Piece* shall be externally coated with a corrosion protection coating compatible with the corresponding riser coating, per [5].

If high strength steel studs are approved to be used in the compact flanges instead of titanium, the carbon steel side of the stud and nuts shall have electrical contact with the *CS Compact Flange* to provide cathodic protection for these studs and nuts in case of water permeation through the rubber coating.

The outer surface of the *Transition Spool* and steel flanges (excluding face of flange, encapsulated areas, and areas near weld preps) shall be coated in accordance with PETROBRAS specification [5].

UNS N06625 alloy inlays shall be applied to the sealing surfaces and grooves of the steel flanges faces.

UNS N06625 alloy inlays shall also be applied in the carbon steel parts (*Lower Flange*, *Pup Piece* and riser pipe), in a minimum length of 10 meters from the flange interface, for any inner diameter, when un-cladded carbon steel riser is specified, to provide a galvanic buffer between the titanium and carbon steel. For the same reason, the inner diameter of the steel *Transition Spool* shall be entirely cladded in any case. Moreover, for the steel *Transition Spool*, combination of welded forgings (extremities) and pipe may be considered. Requirements for the pipe section of the *Transition Spool*, including acceptable CRA inlays, per [3].

Requirements for CRA weld overlay on steel (forged) parts are show in section 8.6.

All coatings and coating procedures used by SUPPLIER or SUB–SUPPLIERS are subject to the PETROBRAS's review and approval. Qualification of personnel as per [5].

8. MANUFACTURING REQUIREMENTS

Components shall be manufactured as per SUPPLIER drawings approved by PETROBRAS. The requirements established in [61] shall be complied by SUPPLIER and SUB–SUPPLIERs. Components may be produced by open or closed die forging, ring rolling, extrusion, or by hot rolled seamless tubular processing. Pipe and flange components shall be final forged or extruded from input billet, which has been forged in the alpha/beta range.

Pipe and flanges shall be seamless and either:

- Beta processed and stress relieved;
- Alpha/beta processed followed by a beta anneal and stress relieved.

Both processes shall be followed by machining both the OD and ID. Components shall be free of alpha case.

Titanium welds are not permitted.

8.1. MELTING, CHEMICAL COMPOSITION

8.1.1. Melting

For titanium material, ingots shall be multiple melted in accordance with the melt practice of [56]. The final melting cycle shall be under vacuum. The first melt shall be made by vacuum consumable electrode, non-consumable electrode, electron beam cold hearth, or plasma arc cold hearth melting practice. The subsequent melt or melts shall be made using vacuum arc re–melting practice.

8.1.2. Chemical Composition

The chemical composition of titanium shall comply with [40], alloys Grade F23 or Grade F29, with extra-low interstitial elements. The specific grade selected for the Project shall be detailed on the engineering component drawing.

The hydrogen content shall be tested and reported on the final product after any heavy pickling, if applicable. (It is permissible to sample for final hydrogen prior to a wash pickle provided that the wash pickle is limited to 0.002” per surface removal or less).

Weight percentile composition of main alloy elements shall be informed, as well as other residual elements with concentration level greater than 0.1% (individual) or 0.4% (total). In addition, the report shall include the percentile composition of the following interstitial elements: carbon, oxygen, nitrogen, hydrogen and iron. Other elements may be also reported at the discretion of SUPPLIER.

8.2. HEAT TREATMENT

Heat treatment shall be optimized to produce a uniform fully transformed beta microstructure.

Acceptable heat treatment processes are as follows:

- Quality heat treatment of QTS's and heavy-wall seamless-tubular products or forgings conducted in furnaces meeting the requirements of [57];
- Quality heat treatment of QTS's and heavy-wall seamless-tubular products or forgings in furnaces meeting the requirements of [58], except that the furnace uniformity tolerance is limited to plus or minus 15°C;
- Quality heat treatment of QTS's and heavy-wall seamless-tubular products or forgings in furnaces with load thermocouples attached to all parts (including QTS's). All parts and QTS's shall be maintained at the selected temperature plus or minus 15ºC.

Heat-treatment furnace records or charts shall be maintained showing time and temperature for all heat-treatment operations. Heat-treatment temperature and cycle times, furnace identification, and processing equipment identification, if applicable, as well as a description of the methods of cooling, shall be stated in the documentation package for each heat and heat treat lot for all heat treatment cycles.

8.3. TITANIUM QUALIFICATION TEST SAMPLES (QTS)

A QTS shall be utilized to qualify the mechanical properties of components based on a per heat – per heat treat lot basis. The QTS shall be a prolongation extending from one or both ends of the component. All test specimens shall be sub-sectioned from the QTS based on the final machined size of the component.

A QTS shall be used to qualify the mechanical properties of all forgings on a lot basis.

The thickness, upon which the dimensions of the QTS are based, shall be defined as the diameter of the largest circle that can be inscribed within the critical section for mechanical properties or the structural weld thickness, as appropriate.

- If more than one critical section for mechanical properties has been identified for forging on SUPPLIER drawings, then the thickest critical section for mechanical properties shall be used as the basis for defining QTS size requirements;

- If more than one structural weld thickness has been identified on SUPPLIER drawings, then the thickest weld shall be used as the basis for defining QTS size requirements;
- If both critical sections for mechanical properties and structural weld thicknesses have been identified, then one of the following options shall be adhered to:
  - one QTS based on the maximum thickness determined above;
  - two QTS, one with a thickness based on the maximum critical section for mechanical properties and one with a thickness based on the maximum structural weld thickness;
  - a stepped QTS containing thicknesses based on both the maximum critical section for mechanical properties and the maximum structural weld thickness;

QTS shall comply with the following requirement:

- The length of that sample shall be such that all test specimens can be taken from an area at least one times thickness from any forging end.

QTS shall have a suitable hot work ratio to qualify all parts represented.

QTS shall accompany the forging they represent through all heat treatment cycles.

QTS configuration and dimensions shall be approved by PETROBRAS and fully described in the documentation package.

8.4. MECHANICAL PROPERTIES

Test results shall comply with the minimum values of tensile requirements established in [38], [39] or [40], up to the stated cross section limit. Mechanical properties different from those shall be justified in the Design Basis and Methodology.

8.5. STEEL FORGINGS

8.5.1. Material

Forging materials shall comply to section 8 of [19] with additional or modified requirements bellow:

- Test Temperature for Charpy Impact Testing shall comply with [21];
  - Requirements from [31] shall be fulfilled considering de class indicated on Project Data Sheet [4] for each Stress Joint type. The hardness after all fabrication steps shall not exceed 230HV10 for Class 3 Flexible Joints and 250HV10 for other cases;
  - SSC Testing shall be executed in accordance with general instructions declared in section 8 of [19], if exposed to the predicted fluid;

- Gas Injection Stress Joints, Sulphur content shall not exceed 0.003%. For other CS lines, section 8.3.6.2 of [19] shall be fulfilled;
- In cases where Weld Overlay shall be applied, the requirements stated in section 10.7 shall be complied with;
- For forging with Weld Overlay, no SSC and HIC tests are required to be done, provided that the provisions of section 10.7 are fulfilled.

8.5.2. Qualification Test Sample (QTS)

Quality test Samples shall be used to qualify the mechanical properties of all forgings on a lot basis. QTS shall comply with section 8 of [19].

QTS shall have a suitable hot work ratio to qualify all parts represented.

QTS shall accompany the forging they represent through all heat treatment cycles.

8.6. CRA WELD OVERLAY ON STEEL PARTS

8.6.1. Static Loaded Components

Flange face and groove shall be qualified according to [29] and [51]. The maximum iron content in internal surface shall not exceed 5%wt. Corrosion tests according to section 6.3 of [16] shall be executed. If only some parts of a certain component are static loaded (e.g. Lower CS Compact Flange faces), then the provisions of this Section are limited to the static regions of component.

8.6.2. Dynamic Loaded Components

Dynamic components of a TSJ assembly may include the Lower CS Compact Flange and the Pup Piece.

Weld overlay procedure used to deposit the clad weld shall be qualified in accordance with section 6.2 of [16], if the strengthening effect of clad weld is demanded (see section 4.2).

Weld overlay shall be executed in several welding passes in order to limit the maximum height of welding passes. At least, two welding passes are required. After each pass, a machining and a LP shall be executed. The maximum height of each machined pass shall not be higher than the maximum height of a full circumferential flaw calculated by ECA according to section 7.9.

NOTE 1: Interpass machining is required because conventional volumetric NDT is not able to reliable detect and size (height, length and depth) flaws on weld overlay layers. In this case, several welding passes with interpass machining and LP will limit the maximum height of a non-detected full circumferential flaw in the weld overlay.

NOTE 2: Alternatively to multiple welding passes with interpass machining, a single pass, multiple torch application, with at least two welding layers, may be performed. In this case weld overlay shall be fully inspected by pAUT system qualified according to section 10.7.2. In any case, a final machining and LP of the entire length of the CRA overlaid ID shall be performed.

Acceptable CRA layer thickness measurement techniques, equipment and measurement tolerances according to [41] and [42]. For the steel flange neck and Pup Piece, a minimum of 06 (six) equally spaced thickness measurements along the circumference, every 0.400m in the length of the forging shall be taken. CRA layer thickness shall be determined by the difference of the pre- and post-overlaid measurements done in the same zone.

Each machining step shall be executed with a CNC machine. The CNC machine shall be calibrated every shift.

The inner surface to be in contact with the conveyed fluid shall have Ra roughness lower than 3.2 µm and a maximum Rt of 40 µm. The acceptance criteria for roughness are requested to be fulfilled in overall surface condition. After final machining, the weld profile (weld bead) shall not be visible and the surface shall be free from any kind of grooves or any other stress concentration areas, as steps due to start / stop and repairs.

Pickling shall be performed. The pickling solution to be applied shall fulfil the requirements of Item C.6.1, Table A1.1 of [45]. Subsequent rinsing shall be performed using water with low chloride content.

8.6.3. Corrosion Tests

Corrosion tests according to section 6.3 of [16] shall be executed.

9. INSPECTION AND MATERIAL TESTING OF TITANIUM PARTS

9.1. TENSILE TESTING

Testing shall be in accordance with [37], round specimens tested at room temperature;

- <u>Pipe Components:</u> tensile tests shall be from the mid wall location, longitudinal orientation, two specimens 180° apart from each end of each extrusion or forging;
- <u>Flange Components:</u> tensile tests shall be from the hub end (large end) prolongation of each flange, transverse orientation, one specimen from the OD, mid wall, and ID. Locations shall approximate the finished dimensions of the flange and not the as-forged part.

9.1.1. DE–RATING MATERIAL PROPERTIES

Tensile test to be performed at room temperature and at the maximum design temperature, per each riser function, to confirm the de–rating material properties of SMYS, SMTS and E-modulus. Previous qualification results of tensile test for the same material and similar or higher temperature than the Project design temperature is accepted. See section 12.

9.2. FRACTURE TOUGHNESS TESTING

Fracture toughness tests shall be performed in accordance with [44] (qualification);

- Pipe Components: one fracture toughness specimen shall be cut and tested from each end of each extrusion/forging via the CT method. Testing may be performed in both L–C and L–R direction, but the test orientation shall be informed in the test reports. Results shall be reported as K_Q, K_{IC}, K_{JQ} or K_{JIC};
- Flange Components: fracture toughness tests shall be cut from the hub end (large end) prolongation of each flange, L–R orientation, mid thickness location. Location shall approximate the finished dimensions of the flange and not the as-forged part. Results shall be reported as either K_Q, K_{IC}, K_{JQ} or K_{JIC}.

9.3. MICROSTRUCTURE

- Pipe Components: 100X photomicrographs shall be prepared from specimens cut from each end of each extrusion/forging in both the longitudinal and transverse directions at OD, mid-wall and ID locations. Locations shall approximate the finished dimensions of the pipe not the as forged part;
- Flange Components: 100X photomicrographs shall be prepared from the hub end prolongation of each flange in both longitudinal and transverse directions at OD, mid-wall and ID locations. Locations shall approximate the finished dimensions of the flange not the as forged part;
- Microstructure Acceptance Criteria: the microstructure shall be fully transformed beta structure and free from intermetallic phases and precipitates. Some grain boundary alpha is acceptable. The surface shall be free of alpha case. No continuous β phase should be present, in order to the prevent a fast pathway for hydrogen diffusion.

9.4. MACROSTRUCTURE

- Pipe Components: three locations, two-inch arcs minimum, spaced 120° apart from each end of each forging/ extrusion shall be examined on the transverse face of the pipe.

- Flange Components: three locations, two-inch arcs minimum, spaced 120° apart from the hub end prolongation shall be examined on the transverse face.
- Macrostructure Acceptance Criteria: etching and examination shall be in accordance with [56]. The etching shall be performed for an enough time to develop a well-defined macrostructure and shall show no imperfections such as unhealed pipe, cracks, porosity, laps, folds, pitted areas, segregation, or inclusions detrimental to usage of the material. The acceptance criteria of the macro grain structure shall be [56] Level 30 or finer. No continuous β phase should be present, in order to the prevent a fast pathway for hydrogen diffusion

9.5. CHEMICAL COMPATIBILITY TEST FOR CONVEYED FLUIDS

The titanium alloy shall be tested for compatibility with Project's main conveyed fluids and injected chemicals (primary constituents with the associated inhibitor or solvents) intended to be injected into the risers. These may basically be weight-loss corrosion testing. The purpose of these tests are i) to verify the compatibility of the SUPPLIER manufactured titanium alloy with the Project fluids that may be harmful to the titanium, and ii) to establish the corrosion-safe limits for fluids concentration and operating temperature to guide the integrity management and operation teams for the risers equipped with titanium equipment. The fluids to be tested should be selected based on SUPPLIER experience, among the ones listed in [2], but shall consider at least the following fluids/ chemicals (if the use is foreseen in the Project, per [2]):

- The main acidizing solutions – halogen, sulfuric and phosphoric acids – at any specified concentration, and with the associated inhibitor and injection temperature (NOTE);
- CO_2, if partial pressure above 80 bars, test at the Project specified pCO_2, water content and temperature(NOTE);
- Methanol as secondary constituent of certain commercial chemicals, if the water content of the mean is less than 15%wt;
- NaOH used for final acid neutralize, at any specified concentration, if pH>10;

NOTE: SUPPLIER shall study the injected concentration and temperature, and if the test fails to guarantee the compatibility, rerun the test as often as necessary, lowering the temperature and the concentration, to establish the safe operational limit for the fluid. The use of SUPPLIER proposed inhibitor should also be considered, since it is demonstrated by test the compatibility with the other fluid constituents (not neutralize or reduce their expected effect).

SUPPLIER shall propose a Chemical Compatibility Test Procedure and shall submit it to PETROBRAS review.

9.6. NON-DESTRUCTIVE EXAMINATIOINS

All component base materials shall be visually, ultrasonically, and liquid penetrant inspected in accordance with the following requirements. In additional, visual inspection shall be done on all components and assembled equipment for conformance to approved drawings.

9.6.1. VISUAL INSPECTION

- Base Material: all components shall be visually inspected in accordance with [50], Article 9 prior to delivery. All products and forgings shall receive VT with 100 percent surface coverage of all accessible surfaces to be free from visible laps, cold shuts, cracks, porosity, slag, excessive scale, and other surface imperfections.

9.6.2. FLUORESCENT DYE PENETRANT EXAMINATION (PT)

- Finish-Machined Base Metal Surfaces: all heavy-wall seamless-tubular products and forgings for which finish machining has been specified shall be examined by wet-fluorescent or wet visible contrast PT in accordance with [59]. Surface coverage shall be 100 percent of finish machined surfaces. Examination shall be conducted after all heat-treatment operations (excluding stress relief). The ID surface shall be tested for 1 x ID size at ends only. PT procedures shall comply with [60] and all visual examination plans shall be approved by Company. Acceptance criteria shall be in accordance with [48].

9.6.3. ULTRASONIC EXAMINATION

Ultrasonic examination of titanium base material (forgings/extrusions and pipe) shall be in accordance with [36] except as modified in this specification. Titanium base material ultrasonic examinations shall be performed by the full immersion ultrasonic method.

Volumetric coverage shall be 100 percent which includes radial longitudinal, circumferential angle beam and axial angle beam scanning directions. Components with an OD/ID ratio greater than 2.0 shall be scanned from the radial longitudinal direction and axial longitudinal direction where practical.

The reference sensitivity for each scan shall be based upon the thickness of the component section at the time of inspection. Table 10.1 defines the reference sensitivity levels for the interrogation depth:

Table 10.1 – Reference Sensitivity Levels

Component Interrogation Depth	FBH or Equivalent Reflector
<2.0”	3/64” dia
2.0” to < 4.0”	5/64” dia
4.0 to 8.0”	8/64” dia

In addition, product shall be examined from the OD at 1-foot increments at 0, 90, 180 and 270 degrees around the circumference with straight-beam transducers to verify wall thickness. In addition, thickness shall be measured in the same manner at thickness transitions in the stress joint.

9.6.3.1. UT PROCEDURE SPECIFICATIONS

Written UT procedure specifications shall be developed showing scan plans, techniques required, accuracy, equipment performance requirements, technique to be employed, and information required to reproduce test results independently. Procedures are subject to the approval of PETROBRAS.

9.6.3.2. UT AND HEAT TREATMENT

UT shall be performed after all tubular forming and post-forming heat treatment (except stress relief).

9.6.3.3. INSPECTOR LEVEL

UT may be conducted by Level I, I, or III inspectors as per [12], however, evaluation of indications shall be performed by Level II or Level III certified inspectors.

9.6.3.4. Inspections Required

The full length of each heavy-wall seamless-tubular product shall be examined from the OD for longitudinally and circumferentially oriented defects with angle-beam transducers. In addition, the full length of each heavy-wall seamless-tubular product shall be examined from the OD with straight beam transducers to verify wall thickness.

9.6.3.5. Equipment Description

As appropriate for each inspection facility, the inspection equipment description shall include:

- General description of the physical equipment (e.g. shape, size, capacity, layout of sensors, multi-channel/ multiplexed description, power supply, special accessories, etc.;
- General equipment operation (e.g., fixed or rotational motions, approximate speeds, frequency response, etc.);
- Test bench electronics, method of detecting and recording discontinuities, and alarm systems;
- Types of sensors and couplers;

- Areas and percentages of material to be inspected (such as ID or OD or both surfaces, full wall, and areas which cannot be fully inspected); and
- Testing location within the facility including the work environment (i.e., lighting, safety, protection from weather, etc.).

9.7. CERTIFICATION AND DOCUMENTATION

A material test report shall be prepared for each individual component that certifies that the forgings supplied have been inspected and tested in accordance with the requirements of this specification and that the results meet the requirements. All test results including failures shall be reported.

The results of all NDT shall be reported in the documentation package for all heavy-wall seamless tubular products and forgings.

10. INSPECTION AND MATERIAL TESTING OF STEEL PARTS

10.1. WITNESS/ MONITORING POINTS AND TESTS

The manufacturing quality, Inspection and Test Plan (ITP) shall include proposals for PETROBRAS Witness, Hold, Review and Monitor points. The ITP for SUPPLIER and its SUBCONTRACTORS shall be submitted for PETROBRAS review and approval prior to the start of production operations. The testing program shall include appropriate tests to assure qualification of the materials, processes, and the completed Stress Joint assembly. All testing procedures are subject to both internal and external QC oversight and verification.

10.2. MILL TEST CERTIFICATES

Mill Test Certificates shall be supplied for metallic materials, which include the following information:

- Steel making process;
- Yield and ultimate tensile strength and % elongation;
- Chemical analysis including carbon equivalent;
- Impact Charpy V-notch, hardness test results and percentage shear;
- CTOD test results for Flexible Joint Extension and Attach Flange.

10.3. CHARPY V-NOTCH IMPACT TEST

Materials shall be selected to prevent brittle fracture. Charpy impact testing shall be performed in accordance with component specifications to verify material and weld toughness in the final delivery condition. The test temperature for Charpy impact testing of forgings shall be in accordance with Table 11.1 considering minimum temperature defined within this same table below. Exceptions to requirements stated may be provided on Project Specific Data Sheet ref. [4].

Table 11.1 – CVN Testing Requirement for All Riser Function

CVN energy absorption avg., [J]	Table 7–5 of [19]	
CVN energy absorption min., [J]		
Tmin	L.A.S.T. (ref. [4])	
CVN Test Temperature	t ≤ 20mm	L.A.S.T.
	20 < t ≤ 40mm	L.A.S.T. minus 10°C
	t > 40mm	L.A.S.T. minus 20°C
Shear Area (Mean/ Individual) [%]	50/40	

10.4. CTOD FRACTURE TOUGHNESS TESTING

CTOD fracture toughness testing shall be performed on the Lower CS Compact Flange forging. A set of 3 longitudinal specimens shall be extracted from the QTS and tested to evaluate the fracture toughness of each forging heat treatment lot. Specimens shall be taken at equal distances around the circumference of the forging (i.e. every 120 degrees) CTOD specimen dimensions, fatigue pre-cracking, and testing shall be in accordance with [34].

Either SE(B) or C(T) type specimens may be utilized. SE(B) specimens shall be Bx2B for thicknesses (B - full thickness) less than 63.5 mm (2.5-inch) but may be BxB for thicknesses greater than or equal to 63.5 mm (2.5-inch).

CTOD specimen orientation shall be such that the long axis of SE(B) specimens is oriented parallel to the tubular axis and the machined notch is oriented perpendicular to tubular external and internal surfaces.

The test temperature shall be the minimum design temperature. The CTOD value shall be greater than or equal to 0.38mm.

After testing, all specimens shall be subjected to the validity checks of [34]. Significance of pop-ins shall be assessing as described in [34], Paragraph 9.1.3.

If a test fails to meet the requirements, two re-tests shall be performed (for the failed test only) on samples taken from same QTS. Both re-tests shall meet the specified requirements. Forging shall be rejected if one or both re-tests do not meet the specified requirements.

10.5. ULTRASONIC EXAMINATION

Each forging shall be ultrasonically examined in accordance with [33] and the supplementary requirements of [19], App D sect D.4 or D.5 (for receptacle cast).

Acceptance criteria shall be as per [19], App D sect D.4.5 or D.5.6 (for receptacle cast).

10.6. MAGNETIC PARTICLE INSPECTION

All forgings, for which finish machining has been specified, shall be examined by wet magnetic particle Testing (MT) in accordance with [35]. DC magnetizing prods shall not be allowed. Examination shall be performed after final heat treatment final and machining processes.

Surface coverage shall be 100 percent of finish-machined surfaces with magnetization in at least two mutually perpendicular directions (circumferential and longitudinal for hollow cylinders or tubulars).

Examination shall be conducted after all heat treatment operations (excluding stress relief) have been completed. MT procedures and magnetization plans shall be approved by PETROBRAS.

Remnant magnetic field strength (residual magnetism) shall not exceed 800A/m subsequent to MT.

Acceptance criteria shall be in accordance with [19], Appendix D, section D.4.5 or D.5.6 (for receptacle cast).

10.7. WELD OVERLAY

10.7.1. NDT

Weld overlay shall be inspected as [19], Appendix D, section D.3 where applicable. Acceptance criteria as per [19] Appendix D, section D.3.6.

10.7.2. AUT QUALIFICATION TESTING (when required in section 8.6.2)

SUPPLIER shall adopt a suitable Phased Array Ultrasonic system (pAUT) in order to detect lack of fusion and other planar/volumetric flaws within weld overlay.

pAUT qualification requirements shall comply with sections 6.5.2, 6.5.5 and 6.5.6 of [16].

10.8. INSPECTION AND TEST REPORTS

Each test performed shall result in a test report and a quality assurance inspection report, which shall be issued to PETROBRAS within two weeks of test completion.

10.9. QUALIFICATION AND CERTIFICATION OF INSPECTORS

Personnel qualification of Weld, NDT and dimensional inspectors shall comply with [19], and the modifications detailed in [12].

Personal qualification for painting operator and inspector shall comply with sections 10.2.2 and 10.2.5 of [67], and the modifications detailed in the section on the “Requirements for Painting Systems”, of the Coating Assessment for the Project [5].

Qualification of metal spray operators shall be in accordance with item 10.2.3 of [67].

11. COMPONENT TESTING REQUIREMENTS

All components shall pass visual, ultrasonic, and liquid penetrant inspection in accordance with SUPPLIER and this specification prior the assembly of the TSJ. In additional, final visual inspection shall be done on the assembled equipment for conformance to PETROBRAS approved drawings.

All assembly and testing shall be done according to a Company approved Inspection Test Plan (ITP) to ensure quality and safety standards are met.

11.1. FACTORY ACCEPTANCE TEST

Before the final release and packaging, the *Stress Joint* will undergo final testing and review to assure all pertinent aspects of the design and fabrication are following both the PETROBRAS's specifications and SUPPLIER's design and production requirements.

SUPPLIER shall propose a factory acceptance test program for PETROBRAS acceptance to be carried out in detail on the Stress Joint and a fit-up procedure to demonstrate mating to the receptacles. The factory acceptance test program will include as a minimum requirement the steps outlined in hereunder and shall accomplish the following goals:

- Demonstrate compliance with performance requirements described in this Specification and SUPPLIER design and test specification.
- Detect any unit that fails to meet required performance levels and reject them for release unless the non-conformance can be eliminated through re-qualification or mutual written consent from the PETROBRAS.

The factory acceptance test program shall include as a minimum requirement the steps outlined in hereunder:

- Dimensional check of main, interfacing dimensions;
- Electrical isolation of all titanium studs of the *Compact Flanges*;
- Electrical isolation test of the external coating;
- Leak test of the assembled *Compact Flange*, as per sec. 4.6 of [67] and [53];
- Hydrostatic test (as detailed in section 11.1.1).

SUPPLIER Factory Acceptance Testing (FAT) specification shall include test conditions, procedures, measurements to be taken, and acceptance criteria specifically for the Stress Joint to be manufactured. The FAT specification shall be reviewed and approved by PETROBRAS prior to initiation of factory acceptance testing.

11.1.1. HYDROSTATIC PRESSURE TEST

Hydrostatic testing, as part of the FAT, shall be performed after fabrication on the assembly to demonstrate function and integrity. Hydrostatic testing is not required for individual parts.

Internal hydrostatic tests of the riser Stress Joints shall be performed at 1.5x of the Project design pressure specified in [4] and prior to delivery. Agreement shall be obtained with PETROBRAS's representative that pressure stabilization has occurred before proceeding with the hold period of the pressure test. Test duration for all tests shall be a minimum of thirty (30) minutes after pressure stabilization. All components shall be visually inspected for leaks throughout the test period. The test shall be performed in air to allow visual inspection.

Tests shall be performed with end caps installed on both ends of the riser Stress Joints. Following the completion of the test, SUPPLIER shall be responsible for removing the end cap and the associated heat-affected zone (HAZ) from the lower end of the Extension, leaving a clean straight edge ready for beveling, or testing flange.

The fluid media shall be city tap water (fresh water) and the test temperature shall be ambient (outside approx. 20°C). The acceptance criteria for a successful test shall be no pressure drop due to leakage. A pressure drop of 0.5% of the hydrostatic test pressure due to ambient temperature fluctuation is permitted. Pressure recorders and charts shall be utilized.

11.1.2. Test Documentation

Internal pressure test reports shall include, but not necessarily be limited to, the following information:

- Detailed description of test equipment with diagram of test hook-up, and test procedures;
- Test temperature records;
- Test pressure records;
- Test equipment calibration certificates;
- Test results and interpretation;
- Dead weight Pressure Test records.

Calibration certificates (valid within the previous 6 months) shall be supplied for the temperature recorder, the pressure recorder, and the dead weight tester.

11.2. DIMENSIONAL AND VISUAL INSPECTION

All components shall be dimensionally and visually inspected prior to delivery. Rework or modifications shall not be allowed without PETROBRAS approval. All products and forgings shall be visually inspected with 100% surface coverage of all accessible surfaces to be free from visible laps, cold shuts, cracks, porosity, slag, excessive scale, and other surface imperfections.

11.2.1. Dimensional Inspection

Pipe sections shall be dimensionally inspected or, each end and at the approximate center location for compliance to the PETROBRAS approved. Flanges shall also be dimensionally inspected for compliance to the approved drawing. Reports detailing the actual dimensions shall be provided as part of the MPS.

11.2.2. Visual Inspection

Pipe, flanges and weldments shall be 100% visually inspected on the entire OD and accessible ID surfaces. Any abnormalities, local grind-outs, etc. shall be recorded and documented. This applies even if the area is within the dimensional tolerances. The relative location, length, width and depth of each abnormality shall be recorded. External rubber cover shall be 100% visually inspected for damage as crack or cuts. Repair of the damaged area, if any, is mandatory.

11.2.3. Fasteners

Fasteners shall be 100% visually inspected and dimensionally inspected to PETROBRAS approved drawing by the SUPPLIER, as per [13].

12. QUALIFICATION AND PQT OF TITANIUM STRESS JOINTS

SUPPLIER shall demonstrate that all materials proposed for the Stress Joint are compatible with and qualified for the design service conditions (including design temperatures, pressures and the composition of the conveyed fluids and injected chemicals). It shall also be demonstrated the compatibility with FPU and riser material, and corrosion protection system (galvanic and impressed current).

Any relevant document related to product previous qualification program, declared by SUPPLIER as proof of confidence in the design, including test procedures, acceptance criteria and results shall be submitted for PETROBRAS review and comment before the beginning of the Work.

CONTRACTOR shall produce a “Qualification Dossier”, summarizing the documents mentioned in the paragraph above, to be included within Project’s documentation for reference.

Depending on the selected titanium alloy/ grade, several qualifications shall be completed prior to the start of the Work, as detailed in the following section.

12.1. QUALIFICATION SCOPE

The following qualifications\ tests, considered a minimum requirement for acceptance of the *Stress Joint* design, shall be performed before *Stress Joint* supply, unless otherwise stated below.

12.1.1. Metallic Parts

The test matrix for titanium base material is presented in Table 12.1, comparing the tests required to be performed prior to the start of Work ("Qualification") and those required to be performed during the Work, as part of PQT of titanium forgings.

Table 12.1 – TIPT Titanium Base Material Qualification.

	Tests	ASTM-B381-F29 ASTM-B381-F23(NOTE 1)		Other Titanium Alloys	
		Qualification	PQT	Qualification (NOTE 5)	PQT
a)	Corrosion test, as per the method A of [32]	No	Yes (NOTE 2)	Yes	Yes (NOTE 2)
b)	Chemical compatibility assessment with Project fluids (NOTE 3)	No	Yes	Yes	Yes
c)	Tensile test at higher temperature, to determine the de–rating of material properties of yield strength, tensile strength and E–modulus	No	Yes (NOTE 2)	Yes	Yes (NOTE 2)
d)	S-N fatigue testing, as per [46]	No (NOTE 4)	No	Yes	No
e)	Fracture toughness test, as per [44], and section 9.2	No (NOTE 4)	No	Yes	No
f)	FCG test, as per [47]	No (NOTE 4)	No	Yes	No
g)	Chemical composition (material certificate) as per [40] and sec. 8.1.2	No	Yes	Yes	Yes
h)	Micrography/ macrography, per sec. 9.3 and 9.4	No	Yes	Yes	Yes
i)	Tensile test, as per [37] (min. yield strength @0.2% offset, min. tensile strength, % min. elongation, calculated elastic modulus). Additional test requirements per sec. 9.1. Acceptance criteria per [40]	No	Yes	Yes	Yes
j)	Bend test, as per [50]	No	Yes	Yes	Yes
k)	Density	No	Yes	Yes	Yes

NOTE 1: for Non-NACE application, per Table 6.1.

NOTE 2: these tests may be waived if already performed prior to the start of Work, at SUPPLIER discretion.

NOTE 3: these may basically be weight-loss corrosion tests for the main conveyed fluids and for the chemicals intended to be injected into the risers, as per the requirements of section 9.5. For titanium alloys grade F29 ELI, the chemical compatibility test is not required prior to the start of Work.

NOTE 4: the fatigue related tests, d) to f), may be waived, for unwelded forgings of titanium grade 29 ELI or grade 23 ELI, and in this case the curves qualified by PETROBRAS (JIP coordinated by SwRI [18]) shall be employed.

~~**NOTE 5:** Weight percentile composition of main alloy elements shall be informed, as well as other residual elements with concentration level greater than 0.1% (individual) or 0.4% (total). In addition, the report shall include the percentile composition of the following interstitial elements: carbon, oxygen, nitrogen, hydrogen and iron. Other elements may be also reported at the discretion of SUPPLIER~~. [EXCLUDED]

NOTE 5: For other titanium alloy not framed in grade F29 (UNS R56404) ELI and grade F23 (UNS R56407) ELI (for maximum design temperature up to 70°C), all tests a) to k) shall be performed prior to the BID.

The parameters to be used to assess the similarity between the Project proposed and the qualified alloys shall be the results of tests g) to k), which shall be performed as part of PQT and therefore for whatever alloy is selected.

12.1.2. External Polymeric Coating

All the requirements for coating qualification are presented in [5], for titanium and steel parts in the scope of supply.

All materials used in the fabrication of the *Stress Joint* shall be successfully submitted to qualification testing in accordance with accepted standards or approved SUPPLIER procedures. PETROBRAS shall have access to the material test results for verification prior to commencement of production operations.

13. QUALITY CONTROL AND REPORTING

This section defines the quality assurance requirements to be observed in performance of the procedures defined by this specification.

Quality is a prime consideration for ensuring the structural integrity of the Stress Joints. Inspection of the stress joints in service may not be possible and removal of the riser to repair or replace the stress joint would be extremely costly. SUPPLIER shall demonstrate to PETROBRAS's satisfaction that a quality system is in place to ensure that the stress joints will be manufactured per this specification.

Quality management procedures will be routinely performed in every phase of design and manufacture in accordance with the Quality System Manual. Internal quality standards will comply with ISO 9001.

SUPPLIER shall provide details on its Quality Assurance Program to PETROBRAS prior to issuance of a PURCHASE ORDER.

13.1. QUALITY PLAN AND QUALITY CONTROL PLAN

SUB-SUPPLIER shall produce for SUPPLIER review and approval a project quality plan and a project quality control plan:

Project quality plan	Detail the organization, responsibilities, activities, and an index of referenced and applicable procedures to complete the Work, including that of SUB-SUPPLIERS and SUPPLIER.
Project quality control plan (ITP)	Detail quality control plan and control monitoring to be employed during mobilization, acquisition and reporting phases.

All SUB-SUPPLIERs shall address and resolve any audit reports, recommendations and / or corrective action requests issued by the CONTRACTOR to the satisfaction of the CONTRACTOR and of the PETROBRAS.

The criteria of material SUB-SUPPLIER conformity of [61] shall also be observed.

SUB-SUPPLIERs shall also refer to document "QHSE Management for Suppliers / Subcontractors".

13.2. REPORTS AND RECORDS

Records will be maintained to sufficiently document the performance of each operation required by this specification and to identify all materials used in the processing. These records will be formal documentation (MIPs) containing manufacturing and quality control sign offs for each step of the process. These records are available to the PETROBRAS upon request and are retained by SUPPLIER for a certain period as Contract Specifications (length of time to be confirmed by PETROBRAS prior to award of contract).

The following procedures, reports and records shall be provided to PETROBRAS for review.

- QA/QC procedures; to be submitted to PETROBRAS for review prior to start of design and production work. The plans and procedures shall include, as a minimum, the following elements:
    - Manufacturing ITPs for PETROBRAS to comment (assign inspection points);
    - Material and Process Qualification Plan;
    - Inspection and Test Reports to be provided including all reports defined in this Specification;
    - NDE Procedures;
    - FAT Procedures;
    - Document Control Procedures;
    - Traceability Plan;
    - Non-conformance Procedure including examples of report form to be utilized.
- Design Basis and Methodology (DBM) to be submitted to PETROBRAS for review prior to start of design and production work, as a minimum, includes the following:
    - Design Parameters;
    - Design methodology including FEA tools to be used as agreed by PETROBRAS;
    - Proposed material specifications;
    - Chemical composition and mechanical properties of titanium and steel components (yield strength, tensile strength, percent elongation, area reduction and other required properties);
    - Component material lists and descriptions, including designation of any Proprietary material, whose technical specification may be revised by PETROBRAS in SUPPLIER premises;
    - List of Design Drawings to be provided;
    - Design calculations and reports for each element to be provided.

In bidding phase, in case of direct purchase by PETROBRAS, the following documentations\ information are requested to be issued (Technical Proposal):

- Technical Review, comprised by:
    - Preliminary GA drawings, with the following minimum information: main dimensions, view showing the assembly to the *Hang–off* with *Adapter Bushing* and the maximum free angle, and confirming elevation "A" of Figure 8.1, as per ref. [4];
    - A summary list of material selection of main parts (flanges, other forgings, *Pup Piece* pipe, *Adapter Bushing*, fasteners, coating);
    - Cladding and NDT Procedure Proposal;
    - External coating specification (preliminary);

- Technical notes (Qualification Dossier) of previous design and material qualification tests, as per section 12;
- Any technical clarification and alleged exceptions or request for requirement deviation from Project Specifications (this included);
- Mock–up drawing (preliminary), indicating the typical tolerances (gaps) between TSJ *Adapter Bushing/HOA* and the *Hang–off* in accordance with [8], [9] and [15] (optional, see Table 4.1);
- Pull in head description (optional, see Table 5.1).

- Typical Manufacturing Plan/ Procedure;
- Typical Quality Control\ Management Plan;
- HSE
- Typical ITP;
- Typical NCR form;
- SUB–SUPPLIERs list;

The final documentation of the detailed Project shall include:

- Qualification Dossier, covering the items in section 12;
- Design Basis and Methodology;
- Design Report;
- Material compatibility (galvanic) assessment (if not included within the Deign report);
- Chemical Compatibility Report (with respect to PETROBRAS injected fluid data informed within [4]), and alerts to other harmful fluids and concentrations, listed or not listed in [4], based on SUPPLIER experience;
- Manufacturing Procedure Specification (MPS) to be submitted to PETROBRAS for review prior to start of design and production work, as a minimum, includes the following:
    - Procedures including process control plans;
    - Testing and Inspection Plan with monitoring points identified;
    - Compact Flange assembly, torqueing and pre-loading;
    - Factory acceptance testing.
- Inspection and maintenance manual, as pe section 13.3;

- General assembly drawings of TSJ and mock up drawings, as per section 13.4;
- Inspection and test reports, records, and procedures as defined by this Specification;
- As-built drawings or as-built dimensional reports;
- Solid numeric model of the designed Adapter Bushing, the Steel Bushing and the portion of the TSJ Head within it, in a file format to be agreed.

The QA/QC, DBM and MPS shall be written specifically for the PURCHASE ORDER and shall be approved by PETROBRAS prior to commencement of manufacturing operations.

SUPPLIER shall notify PETROBRAS of any changes in these practices for PETROBRAS review/approval prior to implementation.

Design calculations and reports of the Stress Joint shall be issued to PETROBRAS for review prior to the manufacturing.

Nonconformity reports shall be issued to PETROBRAS within the contractual deadline.

All non-conformity reports, including concession requests, shall be submitted to PETROBRAS for review.

13.3. INSPECTION AND MAINTENANCE MANUAL

SUPPLIER shall present an inspection and maintenance manual for the *Titanium Stress Joints*.

This manual shall present any inspection necessary to avoid the Stress Joint failure during the whole specified project operational life.

Include a Repair Procedure of the external rubber cover.

All necessary tools, inspection methodology, acceptance criteria and inspection interval shall be present in this manual, for each necessary inspection.

A list of possible harmful fluids and operational limits (temperature, potential of the CP, etc.) shall be included as an alert.

13.4. DRAWINGS

Prior to start of manufacture, General Assembly drawings of the TSJ, and if required also the mock–up drawings shall be supplied to PETROBRAS for review. Subsequent revisions to drawings shall also be issued to PETROBRAS for review, as they are prepared. GA drawings for both TSJ and mock–up shall include the following minimum informations:

- Interface, overall dimensions and tolerances (including total length, distance from Lower CS Compact Flange face to riser end, elevation "A", alternative dimension "X" of [15] and clearance "B" of Figure 7.1 or Figure 7.2, Adapter Bushing/ HOA external profile dimension, tolerances and lateral gaps with the *Hang–off*);
    - Presented dimensions and tolerances shall be enough to FPU constructor to design the topside hard pipe spool.
    - A representation of the inner contour of the Project selected *Hang–off* shall be included.
- Position of the CoG (in air and in water);
- Total weights;
- Material identification and source part number;
- Details of handling attachments.
- Details of the rubber and other coatings thicknesses and layers;
- Details of the TSJ temporary (anti–impact) coating: thickness, length and cleat system;
- Dimensional details of the standard flange and test port (if required), or the top interface system selected for the Project;
- Dimension and dimensional tolerance of diameters and thickness (including CRA layer if required) at the *Lower CS Compact Flange* or *Pup Piece* end;
- Detail of the Pup Piece external coating coverage and "cut–back";
- SUPPLIER shall include also fabrication drawings with tolerances of the mock–up(s)/ dummy devices, i.e. TSJ mock–up for *Receptacle*, and/or TSJ mock–up and Dummy HOA for *Support–Tubes*.

~~13.5. PROJECT MANAGEMENT~~

- ~~QHSE/PEP Plans - SUPPLIER shall submit a detailed HSE Plan within two weeks of Purchase Order award and shall submit a detailed Project Execution Plan (PEP) within four weeks of Purchase Order award, for PETROBRAS approval. SUPPLIER's PEP shall be designed to achieve all deliveries in line with PETROBRAS's requirements. SUPPLIER shall also submit a Manufacturing Quality Plan detailing all procurement, manufacturing, and inspection processes and activities for PETROBRAS approval within the contractual deadlines.~~
- ~~Status Report – In case of PETROBRAS direct purchase of TSJ, SUPPLIER shall submit a full status report at least monthly. Additional brief updates at more frequent intervals may be required as needed during design, fabrication, and testing of Stress Joint components.~~

- ~~Organization and Key Personnel - SUPPLIER shall assign key engineering and service personnel to manage and control the Work from start through to final delivery. Such personnel shall not be changed without PETROBRAS notification. Within 02 weeks of receipt of Purchase Order, SUPPLIER shall submit an organization chart defining the reporting structure and shall provide resumes of the proposed key candidates, with others on request, for PETROBRAS approval.~~

- ~~SUPPLIER shall confirm compliance with all the requirements of this document, and the referenced documents during the review of the manufacturing quality plan. Any deviation from the requirements of this document shall be highlighted and forwarded to PETROBRAS for review and approval. In the event of any disparity of information given in this document with any referenced document or standard, written clarification shall be sought from PETROBRAS before proceeding with design and/or fabrication of the *Stress Joints*.~~

- ~~Stress Joint delivery and shipping schedule shall be mutually agreed prior to award of contract.~~

[EXCLUDED]

13.6. TRACEABILITY AND MARKING

13.6.1. RAW MATERIAL

Traceability of components shall be established during fabrication, verified at receiving inspection, and shall be fully documented throughout the entire manufacturing process.

The forger shall have an established material traceability plan. Each forging shall be given a unique serial number. The serial number shall be traceable to the heat number and heat treat batch number. Full traceability shall be maintained with respect to the following, as applicable: Heat, Ingot, Heat-Treat Sequence or lot.

13.6.2. PRODUCT MARKING

The Stress Joint must be stamped for permanent identification, including identifying features such as size, rating, and SUPPLIER's assigned serial number. Additional marking for riser tagging may be required by PETROBRAS, wherefore SUPPLIER shall seek PETROBRAS concordance with the product marking.

NOTE: SUPPLIER may use an individual mark (P/N or S/N) for each fabricated item. This mark, transferred on the associated documentation, allows guaranteeing the traceability.

13.6.3. MANUFACTURING OPERATOR AND INSPECTOR MARKING

On all kind of document (manufacturing or test router, report or ITP), the person who will handle the task shall affix his own mark and signature.

13.7. HANDLING, STORAGE AND SHIPPING

Storage and handling procedures shall provide for techniques and protections to avoid mechanical and weather damage. Lifting and support of the TSJ shall be done in a manner that avoids concentrated loads or single point lifts. Schematic drawing of the support points, lifting points and transport crate shall be included within the handling, storage and shipping procedure.

TSJ systems shall be shipped via steel shipping skids or fully boxed steel beam truss baskets for offshore shipment. Pad eyes and lifting sets shall be designed per [26].

The Stress Joint skid shall be clearly marked by paint stencil to identify the contents by size, serial number, CoG and lifting points. The Stress Joint shall be protected against moisture/corrosion or any foreseeable industrial atmosphere degradation of the rubber cover, if it may be stored in an open air, unprotected area.

13.8. DOCUMENTATION REQUIREMENTS (DATA BOOK)

Copy of a final report for each manufactured TSJ shall be submitted to PETROBRAS for review and approval prior to final acceptance. This report shall contain Purchase Order number, part number, dash number, serial number, actual weight, all material certifications, dimensional verification, test results and on-site verification of current visual examination compliance by site inspectors and surveyors, and shall certify that the product was manufactured and inspected in accordance with the requirements of applicable drawing(s) and this Specification.

Additional documentation shall be submitted in accordance with [2].

SUPPLIER shall submit a detailed description of the manufacturing process.

SUPPLIER shall document the design with drawings and calculations.

All tests and clarifications required for the design acceptance and the evaluation of the Flexible Joint and receptacle shall be submitted.

SUPPLIER shall submit the quality control procedures for PETROBRAS review and approval.

SUPPLIER shall submit document stating all deviations to this Specification.

13.9. INSPECTION AND TEST PLAN

This section concerns the product fabricated by SUPPLIER as well as the product purchased by SUPPLIER.

At the beginning of the Project, within the contractual deadlines, the Inspection and Test Plans (ITP) for all stablished items shall be issued for PETROBRAS comments. SUPPLIER shall obtain with PETROBRAS all self-assigned Inspection points (mainly Hold and Witness points) before the start of the manufactures.

All testing procedures are subject to both internal (SUPPLIER) and external (PETROBRAS or PETROBRAS's representative) Quality Control oversight and verification. PETROBRAS approved procedures shall be issued with reasonable advance before the start of manufacture.

The same document shall be used by the SUPPLIER and its SUB–SUPPLIER.

The following ITP shall be produced:

- Forgings and material testing ITPs;
- Machining ITP(s);
- Weld and Heat treatment ITPs (if permitted);
- NDE ITP
- Coating/ painting ITP;
- Cladding ITP(s) (inner surface cladding and sealing surfaces);
- Stress Joint and Pup Piece ITP (assembly, final painting, FAT and other tests, etc.).

The ITP sums up the inspection points, applied by:

- SUB-SUPPLIER;
- SUPPLIER;
- PETROBRAS and CONTRACTOR;
- 3rd Party Inspection.

The ITP shall be submitted for PETROBRAS review. All PETROBRAS holding and witnessing points shall be confirmed prior to start of manufacturing.

The inspection points are defined hereafter:

Table 10.1 – Inspections Points and Definitions

Inspection Level	Definition
H: Hold Point	A point at which work cannot progress beyond, until the activity has been witnessed or written approval has been given by the parties who have designated the hold point.
W: Witness Point	A point where the opportunity to witness shall be given to the parties who have designated the witness.
W1: FoaK	A Witness Point limited to the First of a Kind event.
M: Monitor Point	Activity surveillance on a random basis to verify compliance with contract specifications and procedures.
R: Review Point	Evaluation of Project generated documentation.

Contractual aspects of the inspections (including notification for inspection issuing deadline and notification date revision) shall adhere to the Contractual Guidance for Quality Management, as [1].